SPATIO-TEMPORAL PATTERNS OF BIOPHYSICAL PARAMETERS IN A MICROTIDAL, BAR-BUILT, SUBTROPICAL ESTUARY OF THE GULF OF MEXICO

A Thesis

by

GEORGE M. GABLE IV

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2007

Major Subject: Wildlife and Fisheries Sciences

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Approved by:

Co-Chairs of Committee,	Daniel L. Roelke
	Stephen E. Davis
Committee Member,	Jay R. Rooker
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ABSTRACT

Spatio-Temporal Patterns of Biophysical Parameters in a Microtidal, Bar-Built, Subtropical Estuary of the Gulf of Mexico. (August 2007)

George M. Gable IV, B.S., Texas A&M University

Co-Chairs of Advisory Committee: Dr. Daniel Roelke
Dr. Stephen Davis

Plankton communities are influenced, in part, by water exchange with adjacent estuarine and oceanic ecosystems. Reduced advective transport through tidal passes or with adjacent bay systems can affect chemical processes and biological interactions, such as nutrient cycling, phytoplankton abundance and productivity, community respiration, and zooplankton biovolume. The most threatened estuarine ecosystems are shallow, bar-built, microtidal estuaries with small water volumes and restricted connections through tidal passes and other water exchange points.

This research explored spatio-temporal trends in plankton communities and the physicochemical environment in Mesquite Bay, Texas a microtidal, bar-built, subtropical estuary in the Gulf of Mexico. This research couples sampling at fixed-stations for multiple physical and biological parameters with high-resolution spatial mapping of physicochemical parameters.

Spatial trends were less in magnitude and affected fewer parameters in fixed station and spatial data. Two dimensional ordination plots indicated spatial heterogeneity with a more pronounced temporal trend affecting parameters including temperature, salinity as

a function of inflow timing, and seasonal wind direction affecting primary production and zooplankton biovolume.

Temperature was positively correlated with gross production and respiration rates during spring and late summer with sporadic positive and negative correlations with phytoplankton biomass. The timing and magnitude of freshwater inflow affected various physicochemical and biological parameters. Higher than 71-year inflow rates resulted in low salinity system wide, with spatial heterogeneity increasing over the course of the study, which was confirmed by spatial maps. Additionally, high inflow rates led to two periods of increased inorganic nutrients and dissolved organic matter. Low salinity periods coincided with persistence of higher turbidity, likely because of decreased sediment flocculation. Gross production was low at this time, and likely from light limitation. Additionally, wind magnitude and direction created spatial heterogeneity in turbidity levels and phytoplankton biomass. Zooplankton biovolume was highest during spring and late summer with high species diversity in total rotifers. Copepod biovolume and phytoplankton biomass were positively correlated. Other zooplankton taxonomic groups exhibited variable correlations with phytoplankton biomass and other taxonomic groups. Further long-term studies are needed to determine interactions of various components of trophic food-webs and account for interannual variability in all system parameters.

DEDICATION

To God,

my adoring wife Anna-Marie,

my family,

and Kasey Whiteman

ACKNOWLEDGEMENTS

Thanks to my advisors, Dr. Dan Roelke, Dr. Steve Davis, and my committee member Dr. Jay Rooker, for each individual's dedicated time, knowledge, and guidance.

The research project would have been significantly harder without the commitment and invaluable assistance of my various field partners: Carrie Miller, Hsiu-Ping Li, Calvin Liu, Captain Mac Gable, and my supportive wife Anna-Marie.

I would like to express my gratitude to the Aransas National Wildlife Refuge's willing personnel for allowing access to refuge amenities and resources. I would also like to give a special thanks to Officer Chris Lesser of the ANWR for his help during mechanical difficulties with boat equipment and for returning my wife and me safely to the refuge.

I would like to thank my family for their support in my pursuit of my passions over the years that culminated in my choice of careers.

My buddy and best friend Kasey Whiteman who through his passionate pursuit of hunting and fishing helped to remind me of my passion for these activities and thus rekindled my desire for my field of study. How 'bout them apples? Apple sauce!

Most of all I would like to thank my best friend, my wife, whose physical and emotional support made hard times bearable.

Special thanks to the projects that funded this research: Guadalupe-Blanco River Authority, U.S. Geological Survey, San Antonio River Authority, U.S. Fish and Wildlife Service, San Antonio Water System, Sea Grant, and Texas Coastal Management Program.

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INTRODUCTION

Estuarine primary producers are diverse, and include phytoplankton, microphytobenthos, macroalgae, and submerged aquatic vegetation. Primary productivity in estuaries is usually high compared to neighboring inland water bodies and the open ocean and this higher productivity is influenced, in part, by interactions between chemical, seasonal, and hydrological processes (Mann 2000). For example, reproductive growth is influenced by the availability of nutrients essential for cell division, which in turn are influenced by seasonally dependant nutrient cycling processes associated with the benthos and introduction of nutrients from freshwater inflows (Jansson 1988; Antia et al. 1991; Duarte 2002; Rodrigues and Williams 2002).

High estuarine primary productivity supports numerous ecologically, economically, and recreationally important species. For example, blue crab (*Callinectes sapidus*), an omnivore that consumes benthic detritus to various shell fish, accounts for an annual average of $1.9 million of Texas' economy and is also a food source for the endangered whooping crane (*Grus americana*) (Cook 2002). In addition, various species of shrimp (both in estuaries and open ocean) gross an average of $14.4 million annually to the Texas economy (Guillory et al. 2001). These estuarine detritovours feed on detritus from macrophytes, such as seagrasses. Similarly, red drum (*Sciaenops ocellatus*) and other recreational and commercial finfish infuse $700 million annually into the Texas economy (Benefield 2001).

This thesis follows the style of *Estuaries*.

Estuarine primary productivity and consumers dependent on this productivity are sensitive to freshwater inflows and associated nutrient and sediment loading (Montagna and Kalke 1992; Mann 2000). In addition, increased water consumption within watersheds and the resulting decrease in freshwater inflow rates can result in salinification. Increased salinity levels can potentially limit the growth rates of algae, increase the persistence of harmful algal blooms, suppress zooplankton grazing, decrease biomass of aquatic macrophytes, increase oyster mortality, increase sedimentation via shifting of the zone of turbidity maximum, thus increasing retention of contaminants in sediments (Buskey et al. 1997; Liu and Buskey 2000; Gillanders and Kingsford 2002). Salinification is exacerbated by anthropogenic increases in nutrient loading and resulting eutrophication. Combined with ratios of limiting nutrients, eutrophication has been shown to substantially increase phytoplankton biomass resulting in decreased light penetration, depletion of oxygen due to death and decay of phytoplankton, eventual succession towards harmful algal blooms, and increased pH causing complexation and binding of contaminants in sediments. Additionally, increased sediment loading rates into estuaries cause increased turbidity, decreased light penetration and water depth, leading to decreased primary production by phytoplankton, seagrass beds, and benthic microalgae (Adams et al. 1992; Gillanders and Kingsford 2002).

While multiple autotrophic components of the food web contribute to productivity, phytoplankton and their dominant predators (i.e. zooplankton) can affect the transfer of energy to higher trophic levels. In general, under non-nutrient limited conditions in estuaries, phytoplankton population dynamics varies as a function of phytoplankton

community composition, residence time, water depth (stratification and mixing), and zooplankton grazing rates (Koseff et al. 1993; Lonsdale et al. 1996; Lehman 2007). Zooplankton assimilation and transfer of energy to higher trophic levels is a function of the comparable growth and reproductive rates, i.e. less than one month (Heinle 1966). Additionally, organic carbon produced by phytoplankton can be labile and is efficiently assimilated by zooplankton for transfer to high trophic levels (Mallin 1994; Mortazavi et al. 2001).

As with many components of estuarine food webs, plankton communities are influenced by the aforementioned anthropogenic processes. For example, salinification can affect the habitat preferences of various species, community composition and diversity, and vertical as well as horizontal migration in the water column for phytoplankton and zooplankton (Patrick 1948; Rogerson and Laybourn-Parry 1992a and 1992b; Gaughan and Potter 1995; Vézina et al. 1995; Dolan and Gallegos 2001; Lougee et al. 2002; Smith and Kemp 2003; Su et al. 2004). Plankton community composition can be an indicator of eutrophication, where the presence of specific taxa are a function of nutrient availability and ratio of limiting nutrients (Anderson et al. 2002). Under high nutrient loading rates during inflow events there is a succession "reset" where dominant phytoplankton communities characterized by less-edible, slower-growing, k-selected species are replaced by highly-edible, fast-growing, r-selected species, which can stimulate secondary production in zooplankton (Buykates and Roelke 2005). Concurrently, nutrient limitation and the ratio of limiting nutrients can lead to succession patterns where k-selected species again become dominant, and in extreme cases can

ultimately favor harmful algal blooms (Anderson et al. 2002). In addition, suspended sediment loads can inhibit phytoplankton biomass production, even under eutrophic conditions (Monbet 1992).

Plankton communities are also influenced by the magnitude and timing of freshwater inflows. Theoretically, modeling studies have shown that bottom-up and top-down controls on plankton dynamics are sensitive to the magnitude, mode, and ratios of various nutrients from freshwater inflows, which influence plankton community dynamics (Roelke 2000). Microcosm studies indicated greater phytoplankton diversity coupled with selective feeding behavior of zooplankton on phytoplankton species of higher food quality under conditions of pulsed inflow, which in turn stimulated zooplankton production and decreased the accumulation of phytoplankton biomass (Buyukates and Roelke 2005a). Finally, field studies indicated increases in edible phytoplankton and secondary zooplankton production in relation to inflow events (Buyukates and Roelke 2005b). These findings confirmed that nutrient loading and episodic flushing rates increased phytoplankton diversity, deterred competitive exclusion by k-selected species, and resulted in greater secondary productivity.

Plankton communities are also influenced by their proximity to other systems through various water exchange points. Reduced advective transport in tidal passes and adjacent bay systems exchange points can affect hydrology. Changes in hydrology can affect trends in water quality, nutrient cycling, phytoplankton abundance and productivity, and zooplankton communities, and thus can influence the recruitment of macrofauna (Matthews 1981; Rooker and Holt 1996; Brown et al. 2000; Mortazavi et al.

2001; Su et al. 2004; Karakassis et al. 2006). Ultimately the most threatened estuarine ecosystems are shallow, bar built, micro tidal estuaries with small volumes of water and restricted connections through tidal passes and other water exchange points (Downing et al. 1999; Lin and Hung 2004).

Spatial and temporal drivers affect multiple processes within coastal ecosystems. The interaction of seasonal temperature changes, timing and intensity of fresh water inflows and sea flows, wind driven forcing, and hydro-meteorological forcing have been shown to be important in estuaries (Hearne and Robson 2002; Sutula et al. 2003; Comín et al. 2004). These drivers can affect the temporal and spatial variability in material exchanges, dynamics of dissolved organic materials, inorganic nutrient cycling, phytoplankton biomass, and zooplankton biomass (Pace et al. 1992; Sutula et al. 2003; Clark et al. 2006).

In this research, I explore the relationships between temporal and spatial trends in plankton communities and characterizations of the physicochemical environment. Fixed station sampling methods of analyzing structural and functional responses of physical and biological components to these processes has had limited applicability to spatial heterogeneity between stations. This is due to the lack of monitoring equipment to offer high-resolution spatial data on physicochemical water parameters. Therefore, my goal is to further the understanding of the temporal and spatial effects of reduced tidal exchanges on water quality, productivity, plankton biomass in a small bar built microtidal estuary in Texas. My specific objectives are:

1. Characterize temporal and spatial trends in water column physicochemical parameters including: temperature, salinity, turbidity, secchi depth, pH, dissolved oxygen (DO), nitrate plus nitrite (NO_3^- plus NO_2^-), ammonium (NH_4^+), and ortho-phosphate (PO_4^{3-}), and biological parameters including: gross production and community respiration, phytoplankton biomass and zooplankton biovolume and composition at 9 fixed stations at approximately monthly time intervals.
2. Characterize temporal and spatial trends in physicochemical parameters using an on-board flow through system (Dataflow) that measures: temperature, salinity, water clarity (beam transmittance), chlorophyll *a* (in-situ fluorescence), and dissolved organic matter (FDOM, in-situ fluorescence).

METHODS

This study focused on Mesquite Bay in the Guadalupe Estuary, a system characterized by reduced inflows, restricted water exchange with adjacent bay systems, and tidal exchanges with the Gulf of Mexico. Nine stations were selected to study the effects of water exchange points and characterize various habitat types including seagrass beds over sand and silt, open substrate next to seagrass beds, and open water habitat (Fig. 1). Samples were collected at the 9 stations at approximately monthly time intervals (Table 1). Sampling stations were selected to characterize various habitat types, and water exchange points and provide a basis to determine spatial heterogeneity in system parameters. Sampling was conducted from November 17, 2004 to October 29, 2005.

Study area and hydraulic characterization

Mesquite Bay (28º08.77′N, 96º50.70′W) is a small embayment (368 km^2) located within the Guadalupe Estuary and separated from the Gulf of Mexico by Matagorda Island (Fig. 1). It ranges in depth from 2 m to < 1 m and is characterized as a positive estuary. Mesquite Bay is bordered by numerous dredge spoil islands along the Gulf Intracoastal Waterway (GIWW) and wetlands of the Blackjack Peninsula and Matagorda Island. Subtidal areas of Mesquite Bay contain oyster reefs, seagrass beds, and unvegetated mud and sand bottom. Minimal exchange with coastal ocean waters occurs through Cedar Bayou Pass, which intermittently connects Mesquite Bay to the Gulf of Mexico.

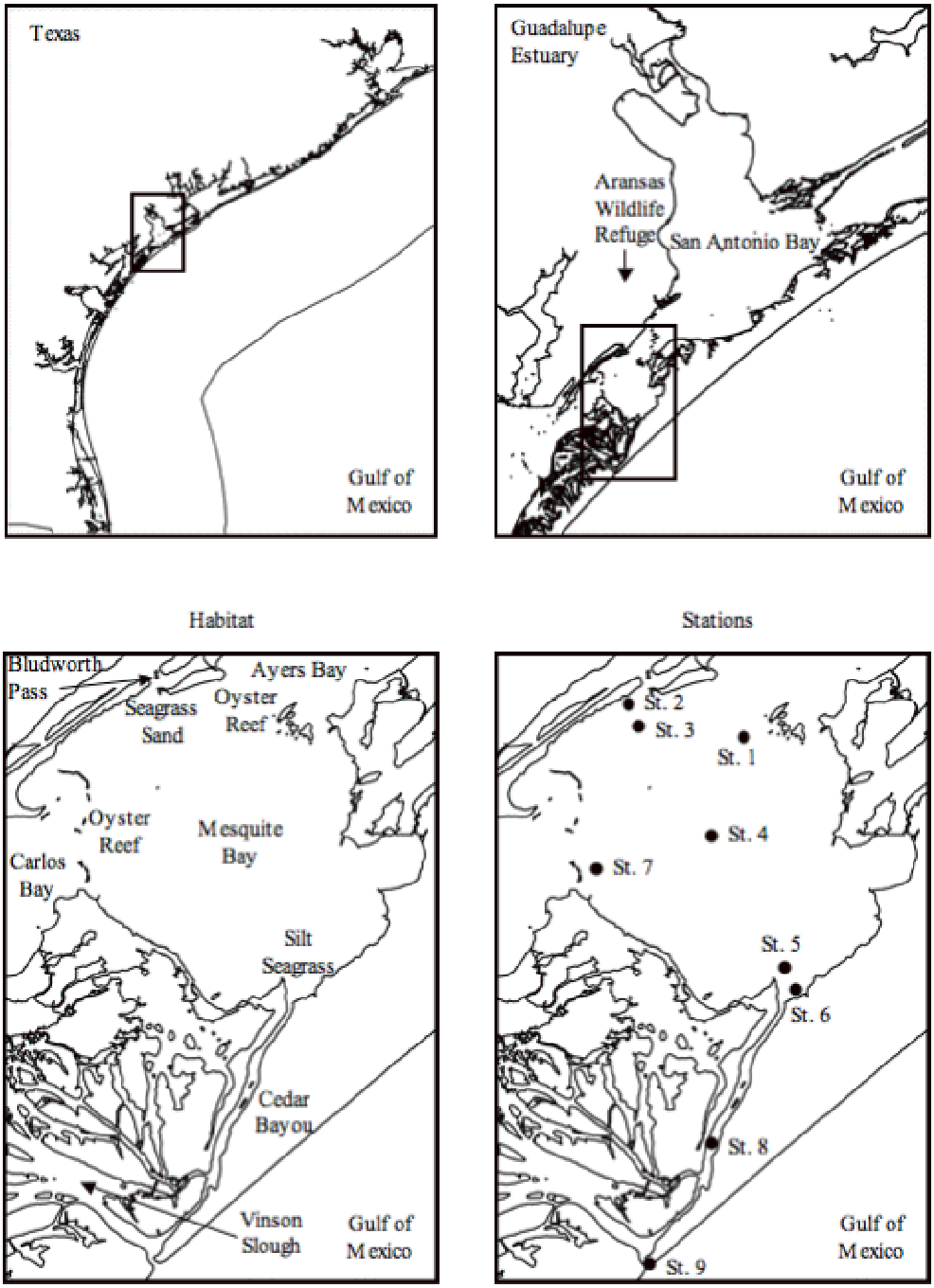


Fig. 1. Map of Mesquite Bay and Cedar Bayou with associated bay systems. Station designations: St. 1 (Station 1), St. 2 (Station 2), St. 3 (Station 3), St. 4 (Station 4), St. 5 (Station 5), St. 6 (Station 6), St. 7 (Station 7), St. 8 (Station 8), St. 9 (Station 9).

This region of the Texas coast is semi-arid, with an average of 82 cm of rainfall per year. The highest daily river inflows generally occur during the fall, and another period of high inflow occurs during the later spring (Fig. 2). Prevailing winds for the region are typically from the southeast ranging on average from 2.2-6.7 m s^{-1} with higher average winds during winter months with sporadic high winds during frontal systems (Bermudez et al. 2005).

Cedar Bayou that links Mesquite Bay to the Gulf of Mexico is approximately 4.8 km long with an average width of 180 m and average depth of approximately 2 m along the northern bayward 3.2 km. The southern 1.6 km gulfside of the bayou is very dynamic with meandering channels and changing morphometry (Bermudez et al. 2005). This southern portion of Cedar Bayou is devoid of saltmarsh, possibly due to constantly changing morphology and erosion. The sedimentation of the pass is hypothesized to be a function of meandering channels, gulf water waves, longshore sediment transport, and hydrology of the internal area of Mesquite Bay and Vinson Slough (Bermudez et al. 2005).

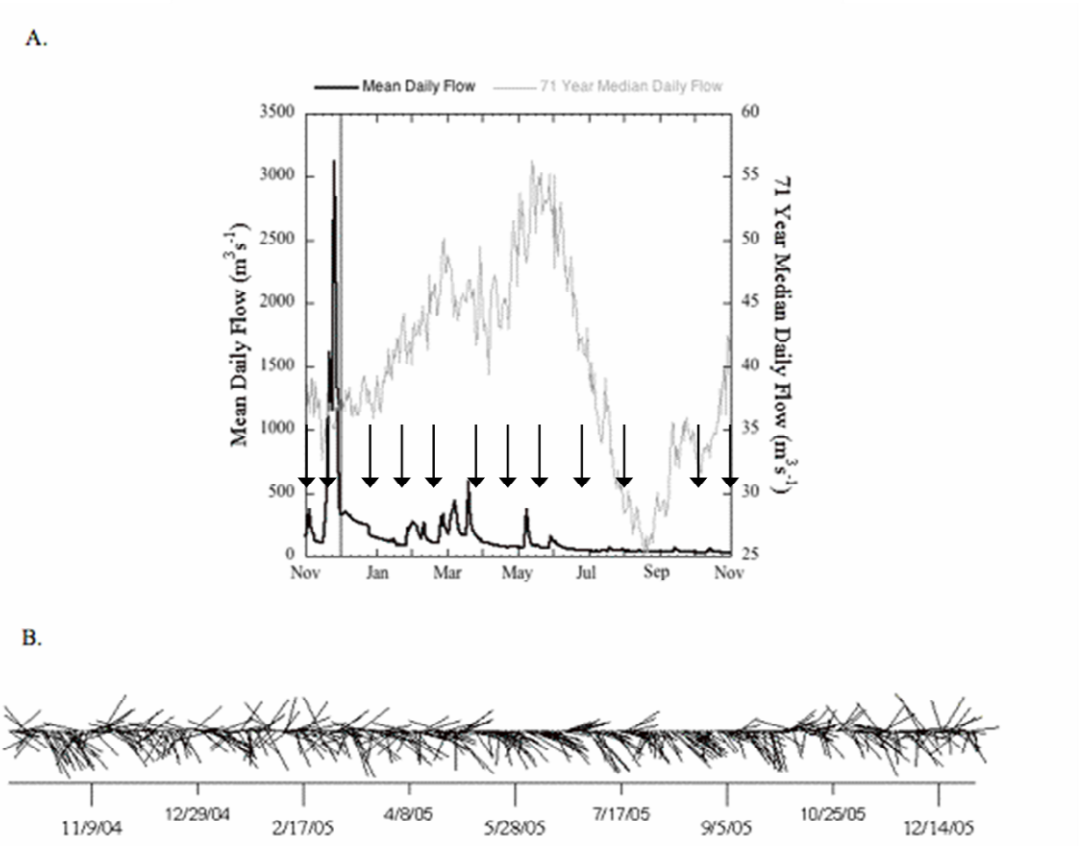


Fig. 2. Panel A: 71-year mean daily flow and sample period flow summed for San Antonio River near Goliad, Texas (USGS Station 08188500), Coleto Creek near Victoria, Texas (USGS Station 08177500), and the Guadalupe River near Victoria, Texas (USGS Station 08176500) from U.S. Geological Survey website. Arrows indicate sampling dates. Panel B: Mean daily wind magnitude and direction for TCOON Station 031 Seadrift, Texas.

Physical water quality parameters

Water quality parameters were measured at each station in the upper 20 cm of the water column and 20 cm above the benthos (except inorganic nutrients). Parameters were measured with a water quality multiprobe (Hydrolab, Inc.) and included temperature, salinity, turbidity, secchi depth, pH, and dissolved oxygen (DO). In addition, salinity was determined using a refractometer and light penetration was estimated using a secchi disk.

Inorganic nutrients

For dissolved inorganic nutrients, 150 mL water samples were filtered through 47 mm glass fiber filters (GF/F). The filtrate was frozen and transported to the laboratory for analysis of nitrate plus nitrite (NO_3^- plus NO_2^-), ammonium (NH_4^+), and ortho-phosphate (PO_4^{3-}) using an auto analyzer (OI Flow Solutions IV, USAEPA methods).

Water column productivity

Gross primary productivity and community respiration were measured using a light and dark bottle technique (Wetzel and Likens 1991), which we adapted to factor in photochemical and peroxidase reactions involving oxygen (Pamatmat 1997). The procedure used five 310 mL borosilicate glass bottles, 3 transparent (light) bottles and 2 opaque (dark) bottles. One transparent and one opaque bottle were used for determination of photochemical and peroxidase oxygen production through chemical poisoning of water samples using 1 mL of concentrated aqueous mercuric chloride.

Incubation bottles were filled just below the surface of the water (20 cm) and bottles were incubated on deck in temperature control baths shielded by neutral density screening (~ 67 % reduction). Incubations typically lasted two hours and spanned the noon hour. An assimilation rate for carbon was determined using reported relationships between oxygen generated during photosynthesis and incorporation of CO_2 (Wetzel and Likens 1991), resulting in values with units of g-C m^2 hr^{-1}. Values in terms of daily productivity were estimated by multiplying by the secchi depth (photic zone) and then by 12 hours (photoperiod).

Phytoplankton biomass

Water samples were collected just below the water surface and aliquots partitioned for analyses of chlorophyll *a* as an indirect measure of biomass. Similar to nutrient analysis, water samples for chlorophyll *a* were filtered through 47 mm GF/Fs, where filters were individually wrapped in aluminum foil, frozen, and transported to the laboratory. Fluorescence methodology was used to measure chlorophyll *a* (EPA 1992).

Zooplankton biovolume and composition

Zooplankton samples were enumerated using inverted phase contrast light microscopy (Utermöhl 1958). Settled volumes ranged from 1 to 55 mL, depending on the amount of detritus in the sample. Zooplankton enumeration and classification was based on measurements at 40x for copepods and 200x for all other zooplankton. At least 100-150 individuals were counted and measured per sample, which often required

multiple settlings for detritus-rich samples. Zooplankton were classified into the following groups: protozoans, rotifers, ostracods, copepods, and polychaetes and nematodes. All groups were identified to the genus level when possible.

Physicochemical water parameters

A flow through Dataflow system developed for mapping physicochemical parameters in shallow water ecosystems was used to generate high-resolution spatial maps of surface water quality during each sampling (Madden and Day 1992). The Dataflow system simultaneously measured water temperature, conductivity, salinity, water clarity (beam transmittance), chlorophyll *a* (in-situ fluorescence), and dissolved organic matter (FDOM, in-situ fluorescence) in 4-second time intervals from approximately 20 cm below the water surface, and each data collection event was geo-referenced. Dataflow voltage output data were adjusted using random spot samples and correlated to generate actual measurements of the aforementioned parameters, excluding FDOM. High-resolution contour maps of each Dataflow parameter were created using Surfer software (v.8).

Statistics

To understand multiple system dynamics within Mesquite Bay, non-metric multidimensional scaling (PC-ORD, v.5) was used. Data arrays for all parameters were created and subjected to relativization by maximum ranking of each parameter and then subject to 10 randomized slow and thorough ordination runs using Sorensen (Bray-

Curtis) distance method. Each run consisted of 250 6-dimensional runs using real data and 250 6-dimensional runs using randomized version of the data array (Monte Carlo Test). Initial runs for dimensionality were subjected to step length criteria of 0.20 and instability criteria over 10 iterations of 0.0. After determination of optimal dimensionality based on stress and instability, additional runs using the recommended number of axes were conducted to generate final ordination, stress, and instability results. See Appendix A for parameter data array structure.

RESULTS

Study area and hydraulic characterization

During the later part of the study, the morphology of Cedar Bayou Pass at Station 9 showed dramatic changes in depth and width (Table 1). At the beginning of the study the pass was ~ 50 m wide with a depth of ~ 1.5 m. On April 23, 2005 the pass was significantly narrower (~ 20 m) and shallower (~ 0.6 m). On May 21, 2005 the pass was only ~ 5 m wide and had a large sand bar present across the mouth with large dead and decaying macrophyte mats lining the shore. These trends could be due to decreased pressure of large inflow events in previous months that created large outflow pressure that was keeping the pass open. On June 22, 2005 the mouth width was ~ 15 m with a depth of ~ 0.5 m and no sand bars present and a small back channel present into Vinson Slough. On July 26, 2005 the pass width was narrower (~ 10 m) and shallower (~ 0.3 m) with the back channel still connected to Vinson Slough. This trend continued until the end of the study.

During the course of the study, freshwater inflows into the Guadalupe Estuary and Mesquite Bay varied from 71-year mean daily inflow rates (Fig. 2). Five sampling dates were above 71-year inflow rates, three sampling dates were below 71-year inflow rates, and four sampling dates were close to 71-year inflow rates. During the winter of 2004, inflows were 4 to 10 times greater than 71-year averages at 3,122 m^3s^{-1}. During the spring of 2005 inflow rates varied from 6 times above 71-year averages at 598 m^3s^{-1} to below 71-year averages at 30 m^3s^{-1} (Fig. 2).

Table 1. Sampling dates, stations sampled, observational environmental conditions, maximum wind speed from Seadrift, Texas TCOON Station 87730371, and observational flow determination at water exchange points in Mesquite Bay, Texas.

Date	Stations Sampled	Skies/ Rain	Wind – Field (TCOON Station 87730371)	Observational Determination Directional Flow
November 17, 2004	1-9	m/c Rain	Moderate - SSE (7.5 m s^{-1})	St 9. Towards Gulf of Mexico
December 16, 2004	1-9	m/c	Moderate - NNE (6.4 m s^{-1})	Undetectable
January 23, 2005	1-9	p/c	Moderate - NE (8.1 m s^{-1})	St 2. Out to ICWW St 9. Out to Gulf of Mexico
February 26, 2005	1-9	m/c	Moderate - NNE (6.4 m s^{-1})	Undetectable
March 26, 2005	1-9	m/c	Slight - NNE (5.1 m s^{-1})	Undetectable
April 23, 2005	1-9	p/c	Heavy - NNE (7.8 m s^{-1})	St. 9 Into pass, macrophytes, pass narrower and shallower
May 21, 2005	1-9	m/c	Moderate - SW (5.7 m s^{-1})	Undetectable, macrophytes, pass narrow and sand bridge at St.9
June 22, 2005	1-9	p/c	Moderate - NNE (6.1 m s^{-1})	St 9. Into pass, macrophytes, pass wider, back channel to Vinson Slough
July 26, 2005	1-9	p/c	Moderate - SSE (8.1 m s^{-1})	St. 9. Pass shallower and narrower, less macrophytes, Vinson Slough still open
August 25, 2005	1-9	p/c	Moderate - SE (6.0 m s^{-1})	St. 2 into MB St. 9. Out to Gulf of Mexico
October 8, 2005	1-9	p/c	Moderate - N (4.3 m s^{-1})	St. 9. Pass ~ 0.30 m deep, Undetectable
October 29, 2005	1-8	Clear	Moderate - NE (5.8 m s^{-1})	Undetectable, motor problems

Physicochemical water parameters

Dataflow spatial maps for water temperature indicated minimal spatial heterogeneity for each month of sampling (e.g., maximum range spanned < 5° C in March 2005), and a pronounced seasonal trend that ranged from ~ 14 to ~ 30 °C. There was little evidence of water exchanges influencing water temperature (see Appendix D).

On the other hand, spatial maps for salinity indicated both temporal trends and spatial heterogeneity within sampling months. Spatial heterogeneity increased from February until June when the range in salinity spanned ~ 22 ppt. Salinity became less variable as the season progressed. Temporal changes in salinity levels ranged from 17 ppt in April 2005 to 4 ppt in August and September 2005. Various dataflow images indicated the effect of water exchange through Bludworth Island Pass and Ayers Reef along with Gulf of Mexico waters through Cedar Bayou on spatial trends in salinity (see Appendix D). Spatial data for salinity and FDOM exhibited a high negative correlation (0.76-0.99) for February to April 2005 suggesting freshwater inflow as a source of FDOM during increase inflow periods.

Spatial maps for water clarity (turbidity as % transmittance) indicated a temporal trend being highest winter, lowest in spring and summer, and increasing during fall. Spatial maps also indicated heterogeneity within sampling months. Monthly images indicated the effect of freshwater inflow through Bludworth Island Pass and Gulf of Mexico waters through Cedar Bayou on spatial trends in turbidity (see Appendix D). Dataflow data for turbidity and salinity exhibited low variable positive and negative correlations suggesting other influential factors. Results for turbidity indicated wind direction and magnitude on each sampling date as a possible factor for spatial trends in each sampling month, which will be analyzed in more detail further below.

Maps for spatial patterns in chlorophyll *a* indicated heterogeneity within sampling months. Temporal trends in chlorophyll *a* were evident with a minor bloom in spring (March 2005), summer bloom (June 2005), and a minor bloom in fall (September 2005).

Heterogeneity ranged from 13 µg L^{-1} (August 2005) to 65 µg L^{-1} (March 2005). Spatial maps for chlorophyll *a* suggest the influence of wind magnitude and direction, water exchange through Bludworth Island Pass, and exchange through Cedar Bayou on spatial heterogeneity in chlorophyll *a* (see Appendix D). Dataflow data for chlorophyll *a* and turbidity exhibited a negative correlation (0.54-0.70) for February, April, September, and October 2005. This trend would suggest the influence of resuspension of benthic microalgae during these months.

Heterogeneity in FDOM spatial maps was also evident. Hydrological trends in FDOM were evident with higher values during high freshwater inflow periods (February-April 2005) as exhibited by aforementioned correlations with salinity. FDOM also increased in June and September 2005. Spatial maps indicated possible correlations with chlorophyll *a* spatial maps (see Appendix D). Dataflow data for chlorophyll *a* and FDOM exhibited negative correlations (0.46 and 0.60) for July and August 2005, respectively. Additionally, negative correlations of FDOM with salinity (0.61 and 0.63, respectively) and positive correlations of salinity with chlorophyll *a* (0.90 and 0.65, respectively) would suggest freshwater intrusion through Carlos Bay at station 7 and thus spatial heterogeneity. Spatial data for chlorophyll *a* and FDOM exhibited positive correlations (0.61 and 0.50, respectively) for April and October 2005. In conjunction, the negative correlations of FDOM and turbidity (0.50 and 0.42, respectively) and negative correlations of turbidity and chlorophyll *a* (0.70 and 0.58, respectively) would suggest the influence of resuspension of benthic microalgae and dissolved organic matter during these months.

Statistics

Non-metric multidimensional scaling was applied to 10 individual runs for ordinations of dimensionality using a data array with all parameters sampled to determine best possible statistical analysis. All non-metric multidimensional scaling runs were analyzed using two-dimensional ordinations graphs to determine spatial and temporal trends in system parameters. Run 2 was selected for statistical analysis of system parameters. Run 2 was representative of two-dimensional graphical ordination results, correlation coefficients using Sorensen (Bray Curtis), Pearson-Kendall correlations of ordination axes, and final stress and instability values. Run 2 resulted in a final stress of 15.9, instability of 0.0, cumulative R^2 of 0.887, with one axis R^2 of 0.671. Two-dimensional ordination results exhibited a strong temporal trend in system parameters. In addition, spatial heterogeneity was evident within seasons and in relation to station location. Stations 2, 3, 8, and 9 varied from other stations suggesting the influence of water exchange at the stations on system parameters.

Ordination results for winter indicated a temporal trend with and increasing spatial heterogeneity in station ordinations from December 2004 to February 2005 (Fig. 3). During December 2005, spatial heterogeneity of station ordinations was minimal with NO_3^- plus NO_2^- as an influential parameter for stations 1-9 and total rotifers for stations 8 and 9 (Fig. 3). Heterogeneity in fixed station data was < 3 ppt for stations 1-7 and 6 ppt for stations 8 and 9. A spike in NO_3^- plus NO_2^- was evident for all stations corresponding with periods of higher inflow (Fig. 4. and Appendix B).

During January 2005 spatial heterogeneity in station ordinations increased with turbidity and total protozoans as an influential parameter for stations 1-7, total rotifers for stations 8 and 9, and NO_3^- plus NO_2^- for stations 1-3, 8, and 9 (Fig. 3). Spikes in turbidity were evident for stations 2-6. Decreases in turbidity for stations 1, 7, 8, and 9 could be due to protection of stations 1, 8, and 9 form northeasterly winds and water depth for station 7 (Fig. 4 and Appendix B). Theoretically, turbidity levels would be hypothesized to be a function of wind speed and fetch where lower and higher wind speeds would yield homogenous turbidity levels while intermediate critical wind speed yielding increased spatial heterogeneity of turbidity levels in relation to fetch (Fig 5 Panel A). However, data for 12 hour (Panel B), 1 day (Panel C), 3 day (Panel D), 7 day (Panel E), and 14 day (Panel F) wind speed/direction and turbidity indicated a minimal relationship associated with fetch on turbidity levels. Each aforementioned time interval indicated various instances where low and high wind speeds resulted in heterogeneity in turbidity levels throughout the system. Additionally, salinity and turbidity indicated no clear trend of salinity induced sediment flocculation for all sampling months (Fig. 4 and Appendix B). Correlations using station data for salinity and turbidity exhibited a negative correlation (0.38-0.66). These trends and results suggest the possible influence of multiple processes on turbidity levels including: wind direction, wind magnitude, fetch, salinity, and substrate composition. Fixed station data indicated increases in total protozoan biovolume for stations 2-7, decreases in NO_3^- plus NO_2^- concentrations for stations 1-9, and increases in total rotifer biovolume for stations 8 and 9 (Fig. 4 and

Appendices B and C). The decrease in NO_3^- plus NO_2^- concentrations suggest nutrient limitation.

Spatial heterogeneity of station ordinations reached a maximum in February 2005 with various influential parameters including: turbidity (stations 1, 4, 5, 7, and 8); NO_3^- plus NO_2^- (stations 2 and 3); and total rotifers for stations 8 and 9 (Fig. 3). Spatial maps for turbidity in February 2005 suggest the influence of wind direction on spatial trends in turbidity (Fig. 6). Spatial heterogeneity in February 2005 coincides with decreases in freshwater inflow rates. Spatial maps for salinity in February 2005 suggest the influence of inflow rate on NO_3^- plus NO_2^- concentrations (Fig. 7). NO_3^- plus NO_2^- and salinity for all stations (excluding station 8) exhibited negative correlations (0.39-0.57). NO_3^- plus NO_2^- and inflow rates for all stations exhibited a positive correlation (0.52-0.89) indicating freshwater inflow as a factor on concentrations of NO_3^- plus NO_2^-. Fixed station data indicated decreases in total rotifer biovolume for stations 8 and 9 (Fig. 4 and Appendix C).

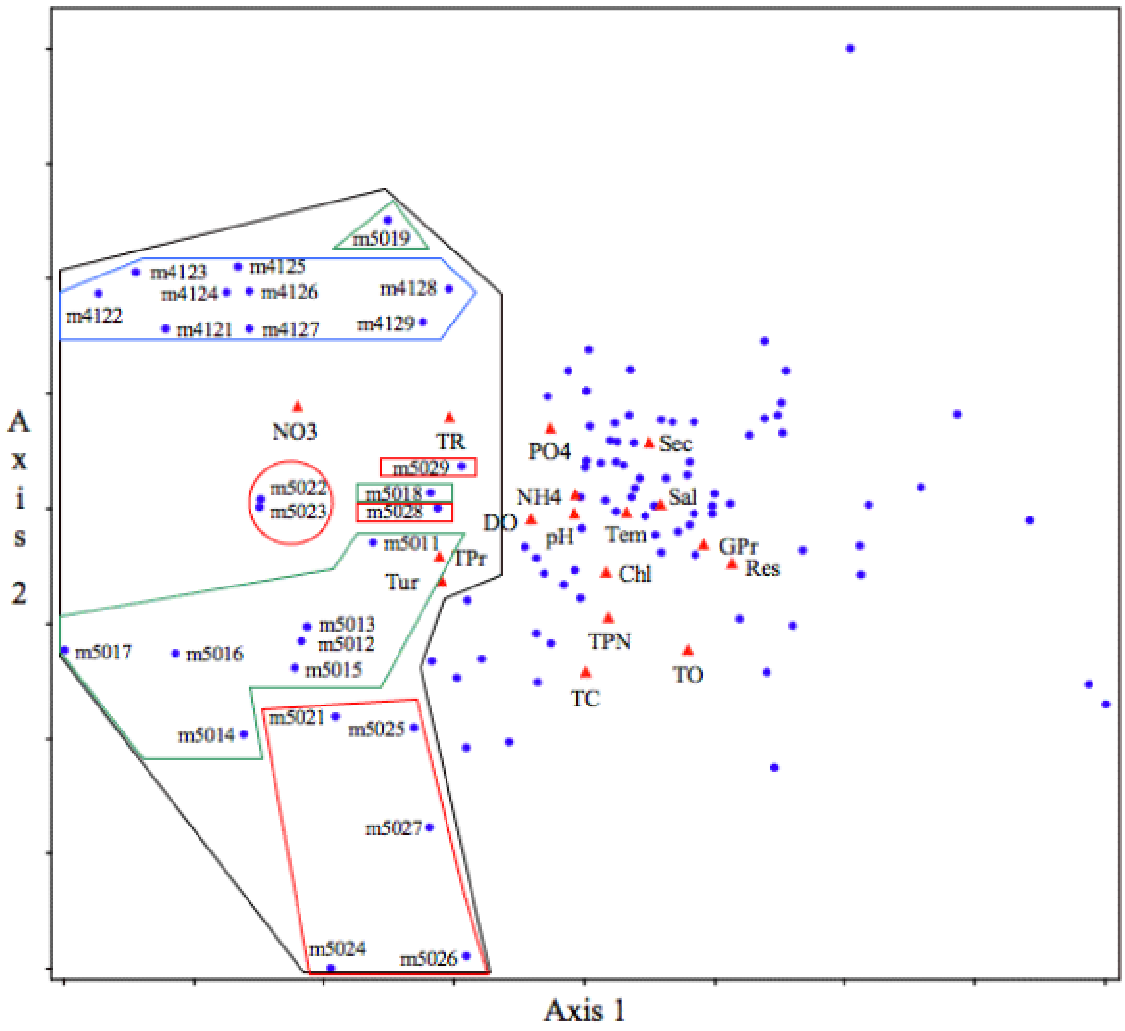


Fig. 3. Spatial representations for two-dimensional, non-metric, multidimensional ordination results for sampled parameters in Mesquite Bay, Texas for winter (December 2004 to February 2005) indicated by the black line. Blue line indicates station ordinations for December 2004. Green lines indicate station ordinations for January 2005. Red lines indicate station ordinations for February 2005.

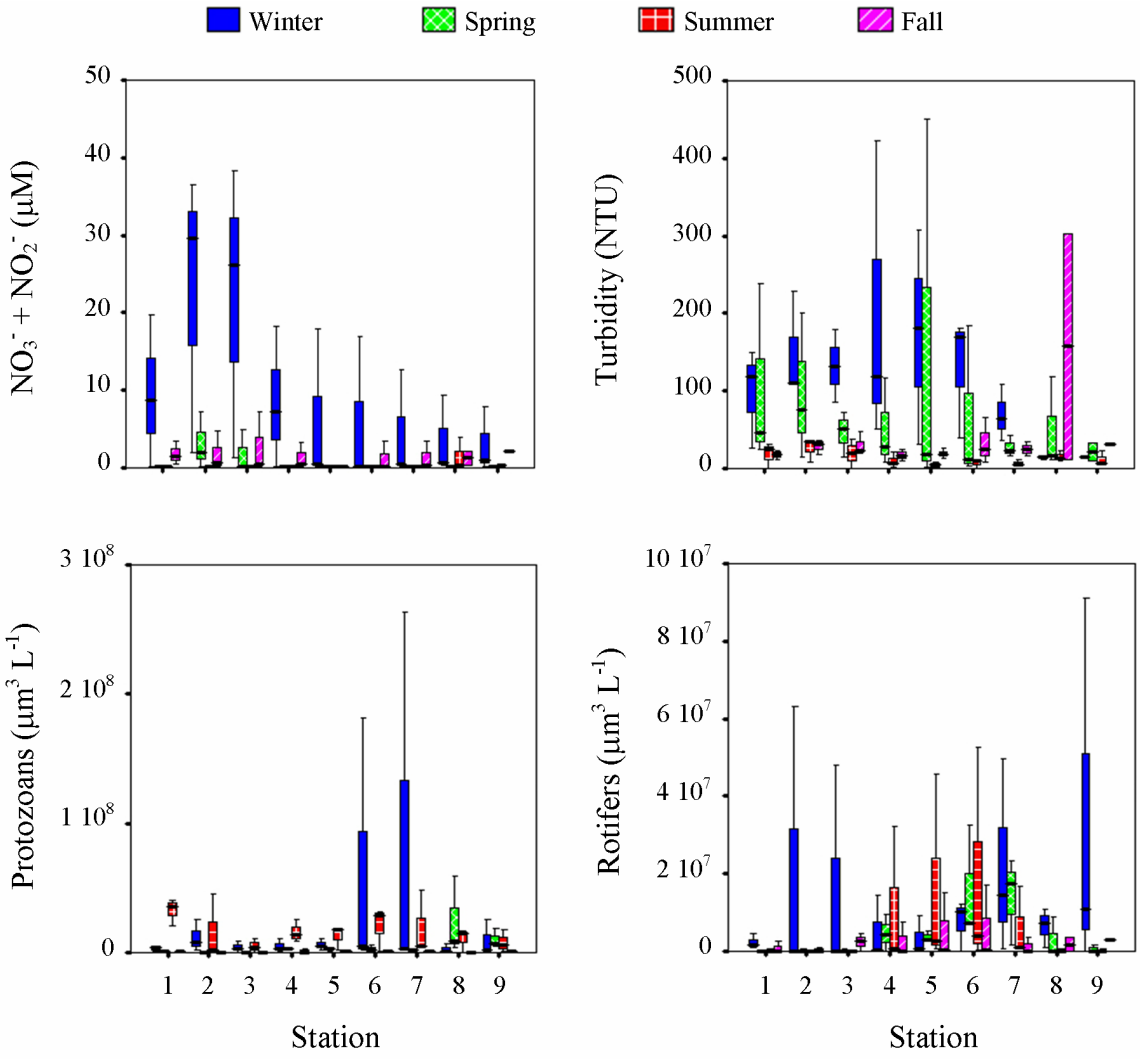


Fig. 4. Seasonal trends for stations 1-9 for NO_3^- plus NO_2^-, turbidity, total protozoan biovolume, and total rotifer biovolume for Mesquite Bay Texas.

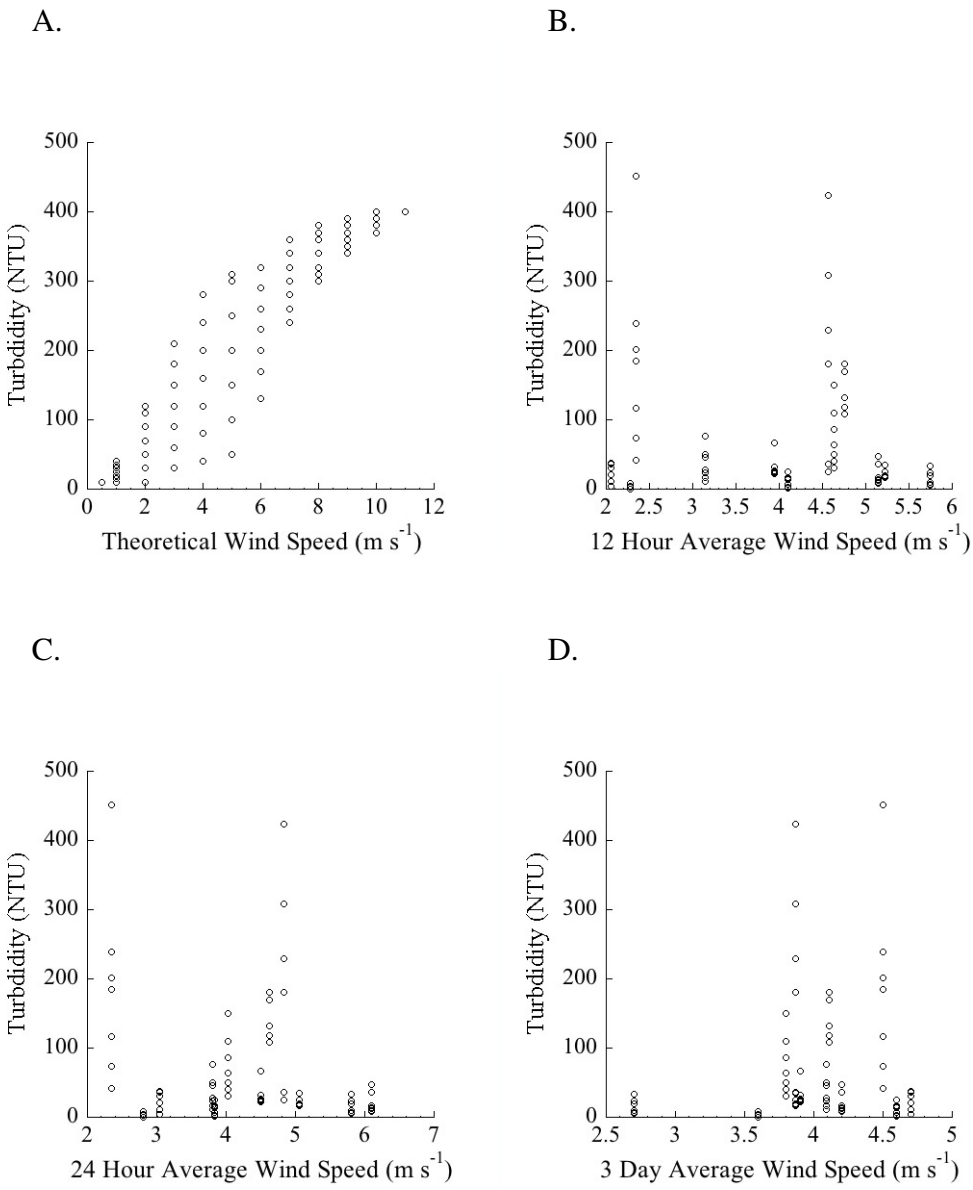
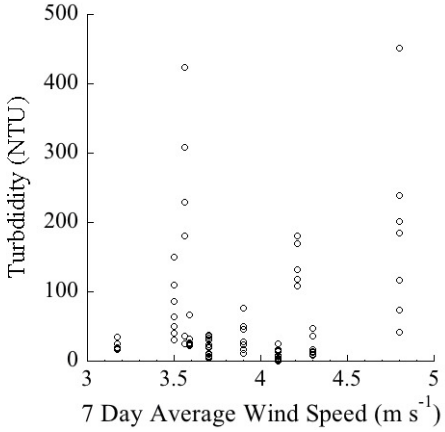


Fig. 5. Theoretical wind speed and turbidity levels (A) at Seadrift, Texas TCOON Station 87730371 average wind velocities and direction for 12 hours (B), 1 day (C), 3 days (D), 7 days (E), and 14 days (F) turbidity levels prior to each sampling date and station specific turbidity levels for Mesquite Bay, Texas.

E.



F.

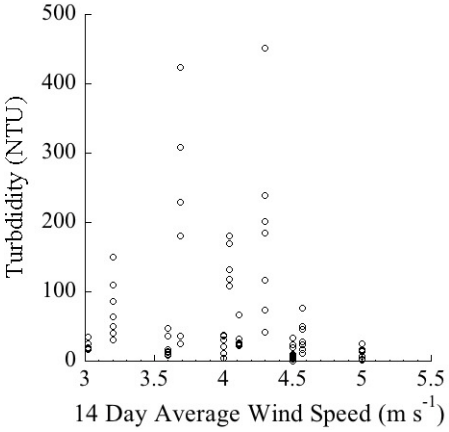


Fig. 5. Continued.

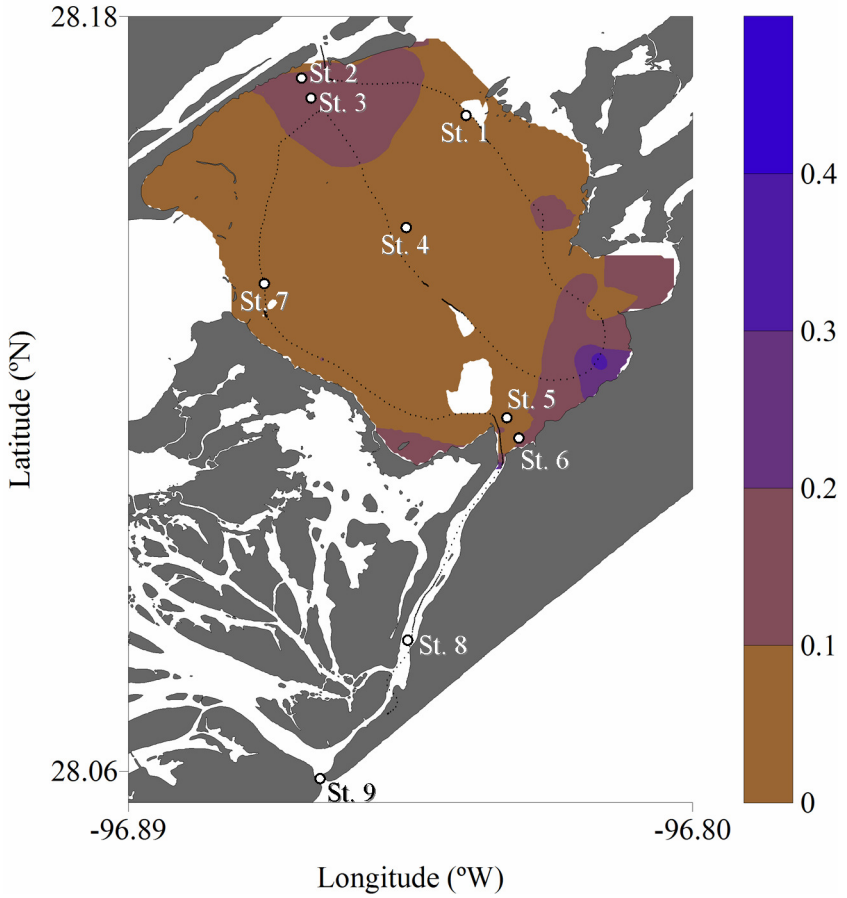


Fig. 6. Spatial interpolation of turbidity (% transmittance) for February 2005 in Mesquite Bay, Texas.

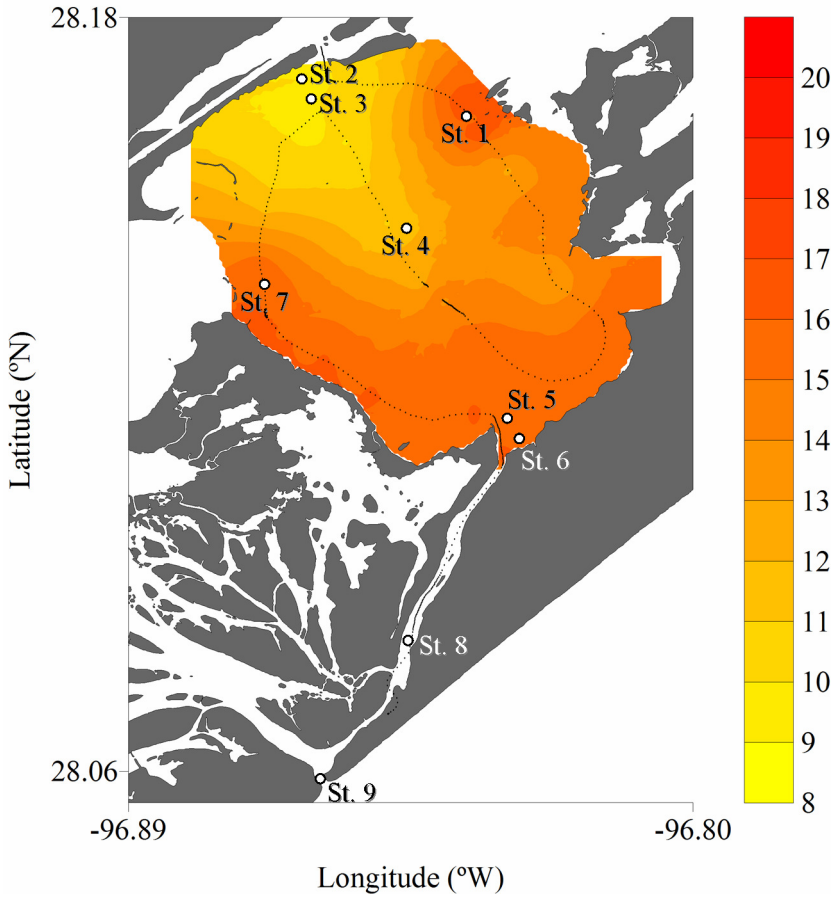


Fig. 7. Spatial interpolation of salinity for February 2005 in Mesquite Bay, Texas.

Ordination results for spring indicated a temporal trend with decreased spatial heterogeneity. Spatial heterogeneity in station ordinations was evident for stations 2, 3, 8, and 9 (Figs. 8). During March 2005 various parameters were influential including: turbidity (stations 2, 3, and 8), chlorophyll *a* (stations 4-7), total copepods (stations 1-3), and total polychaetes and nematodes (stations 5 and 7). Fixed stations data indicated increases in total copepods and total polychaetes and nematodes for the aforementioned

stations during March 2005 (Fig. 9 and Appendix C). Spatial maps for turbidity, salinity, and chlorophyll *a* indicate system wide high turbidity (Fig. 10), water exchange through Bludworth Island pass (Fig. 11), and increases in chlorophyll *a* (Fig. 12).

During April 2005 multiple parameters were influential including: turbidity (stations 1 and 2), chlorophyll *a* (station 7), total copepods (stations 1 and 4-6), total polychaetes and nematodes (stations 4-7), and total ostracods for stations 8 and 9 (Fig. 8). Spatial maps for turbidity, salinity, and chlorophyll *a* indicate system wide high turbidity (Fig. 13), water exchange through Bludworth Island pass (Fig. 14), and decreased chlorophyll *a* for station 7 (Fig. 15). These trends coincide with decreases in chlorophyll *a* concentrations indicated in fixed station data and spatial maps. Fixed station data indicated decreases in copepod and polychaete and nematode biovolume and increases in ostracods biovolume for the aforementioned stations (Fig. 9 and Appendices C and D).

Multiple parameters were influential during May 2005 including: salinity (stations 2-6), temperature (stations 1, 3, 4, and 7), and gross production/respiration fro stations 5, 8, and 9 (Fig. 8). Spatial maps for physicochemical water parameters during May 2005 were incomplete and unusable. Fixed station data indicated lower temperatures for aforementioned stations (Fig. 9 and Appendix B). Station ordinations indicated no taxonomic groups of zooplankton as being influential. Fixed stations' data and spatial maps indicate continued decreases in chlorophyll *a* and zooplankton taxonomic group biovolume (see Appendices C and D).

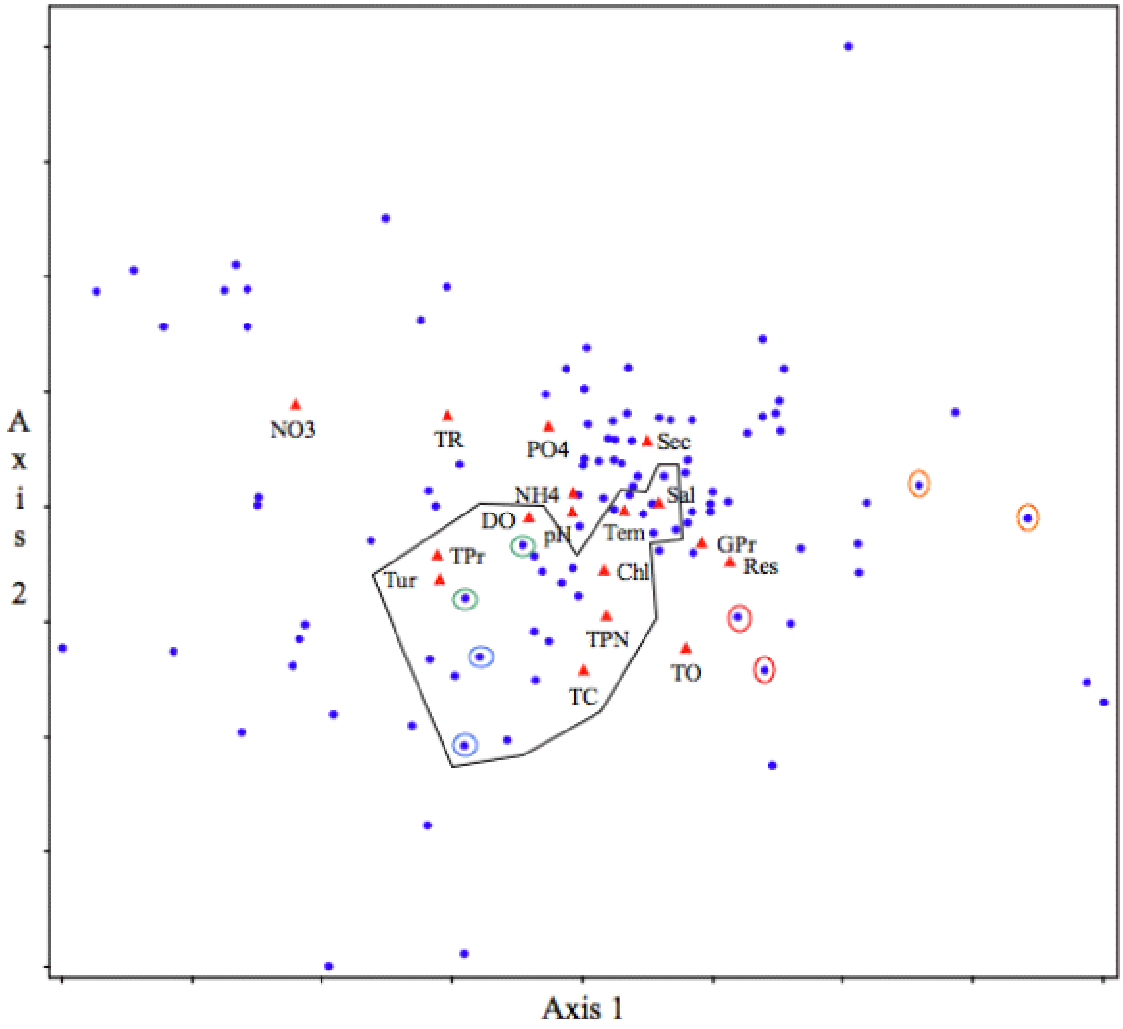


Fig. 8. Two-dimensional, non-metric, multidimensional ordination results for sampled parameters in Mesquite Bay, Texas for spring (March 2005 to May 2005) as indicated by the black lines. Blue ellipses indicate station 2 and 3 ordinations for March 2005. Green ellipses indicate station 2 and 3 ordinations for April 2005. Red ellipses indicate station 8 and 9 ordinations for March 2005. Orange ellipses indicate station 8 and 9 ordinations for May 2005.

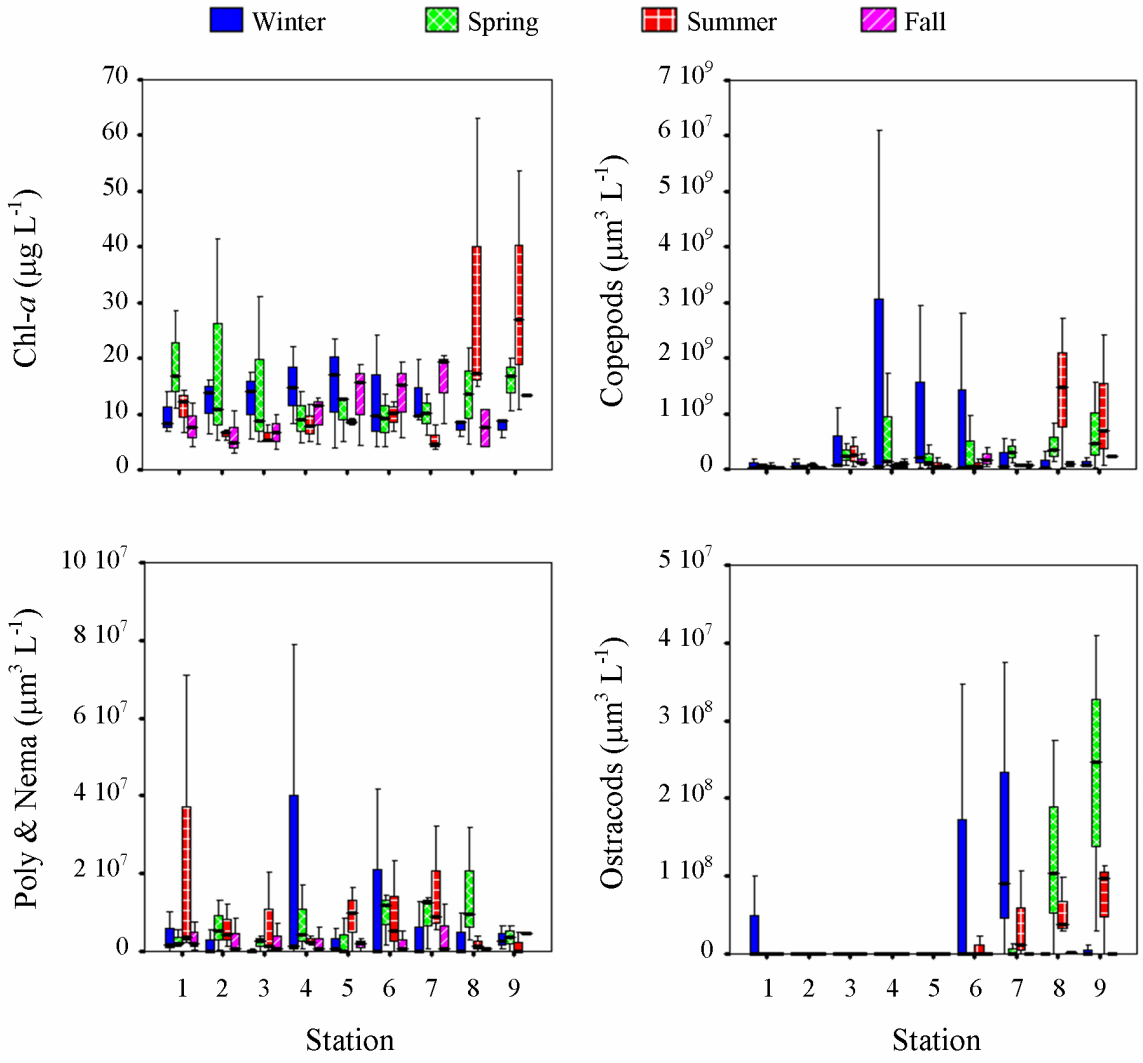


Fig. 9. Seasonal trends for stations 1-9 for chlorophyll *a*, total copepod biovolume, total polychaete/nematode biovolume, total ostracod biovolume, salinity, temperature, gross production rates, and respiration rates for Mesquite Bay Texas.

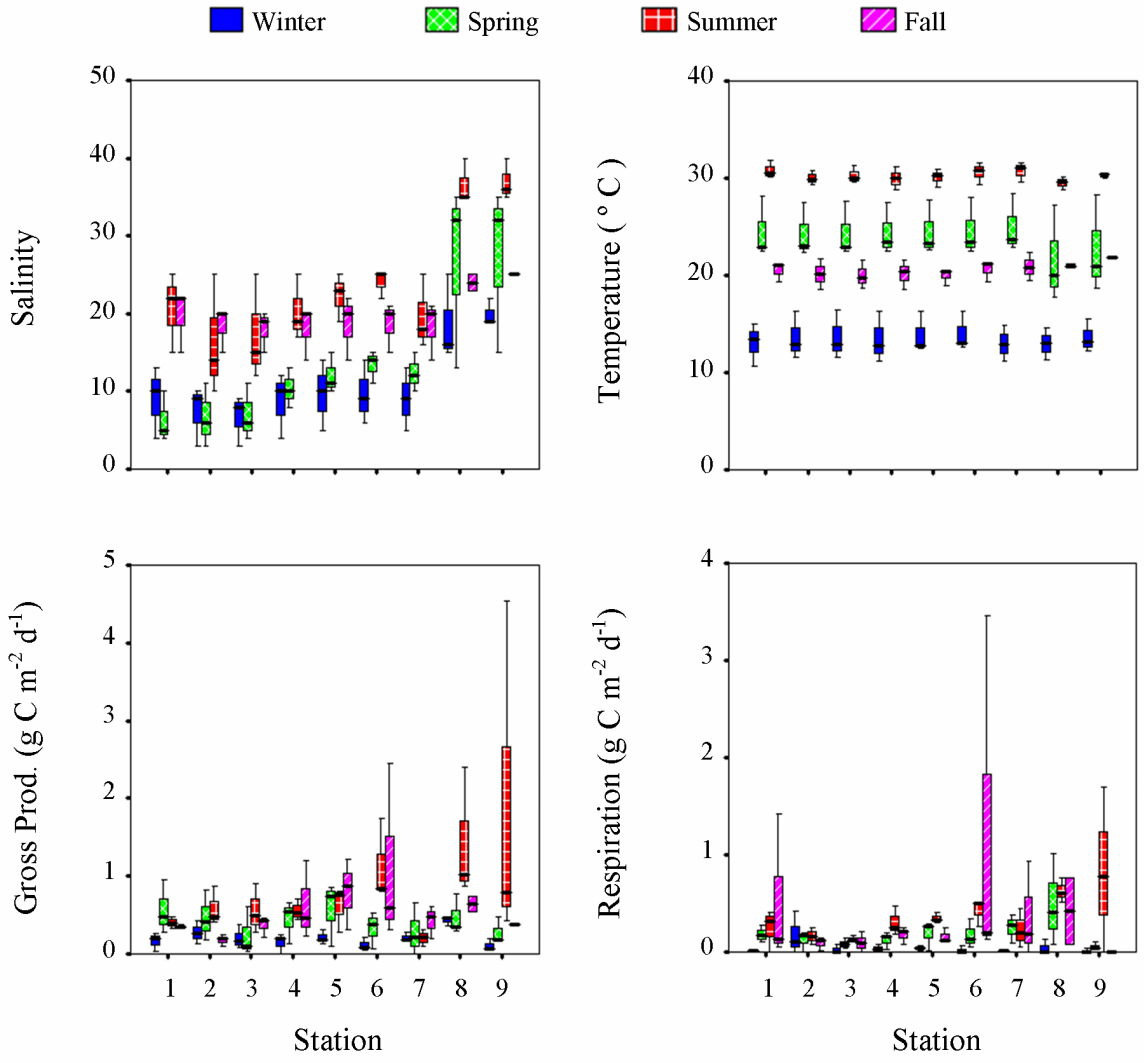


Fig. 9. Continued.

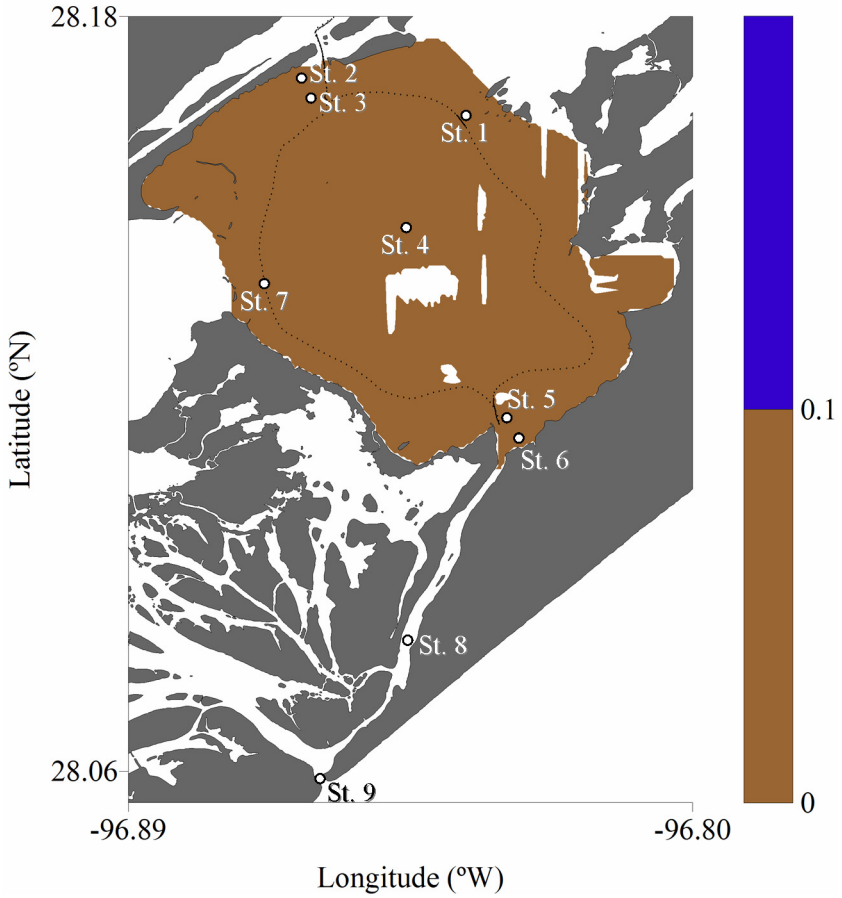


Fig. 10. Spatial interpolation of turbidity (% transmittance) for March 2005 in Mesquite Bay, Texas.

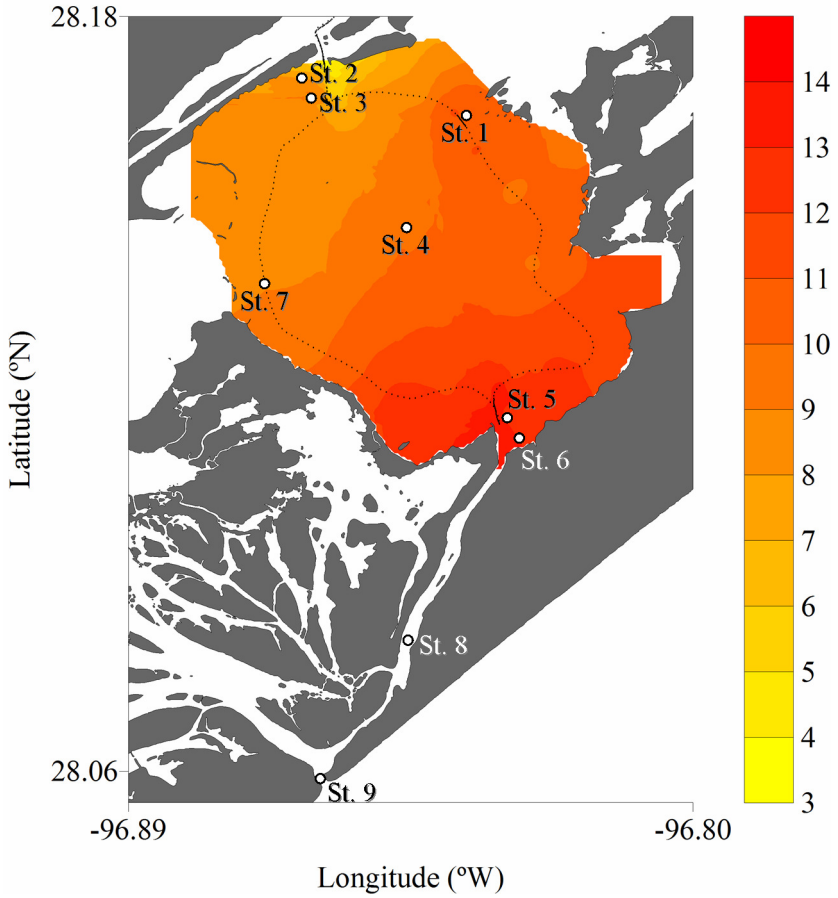


Fig. 11. Spatial interpolation of salinity for March 2005 in Mesquite Bay, Texas.

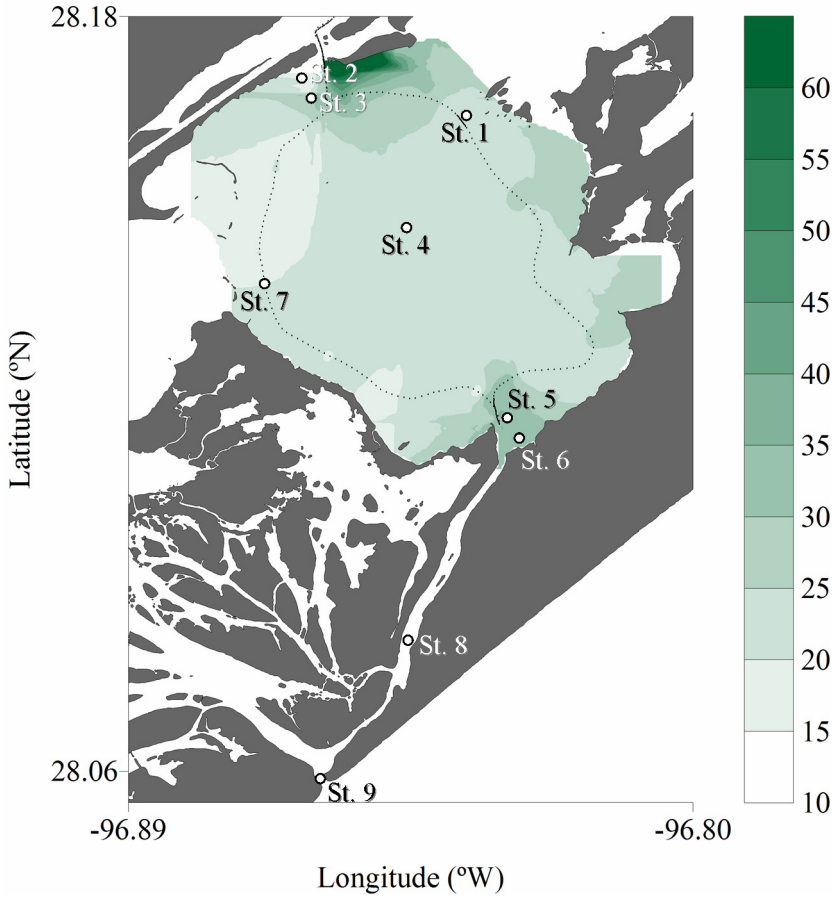


Fig. 12. Spatial interpolation of chlorophyll *a* for March 2005 in Mesquite Bay, Texas.

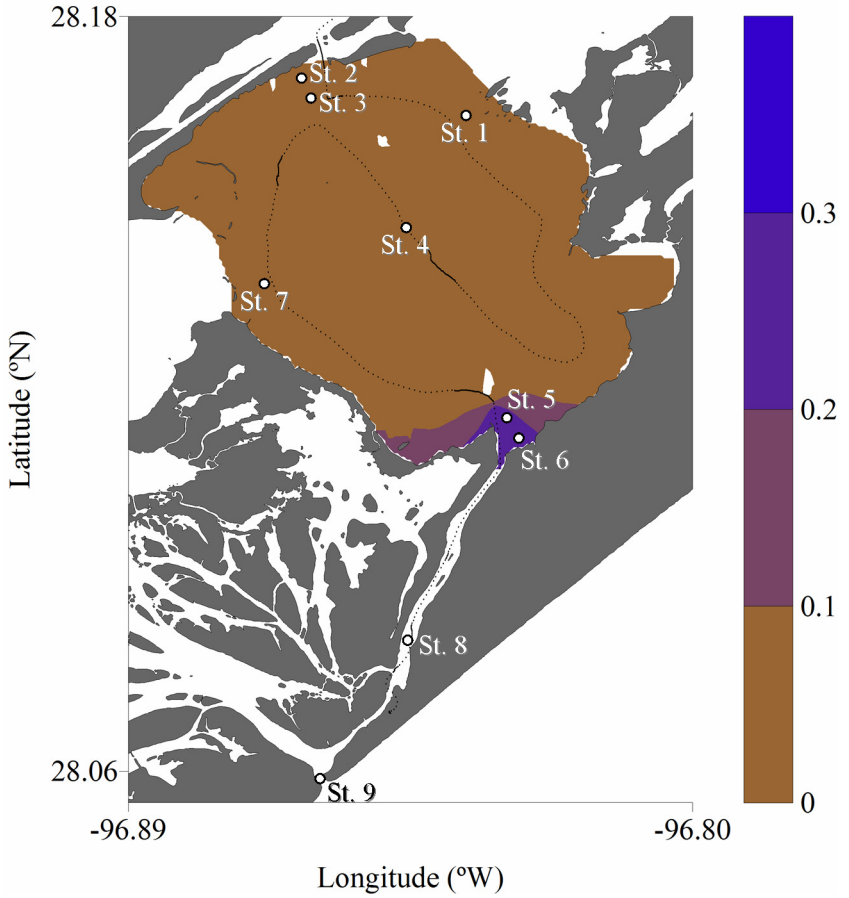


Figure 13. Spatial interpolation of turbidity (% transmittance) for April 2005 in Mesquite Bay, Texas.

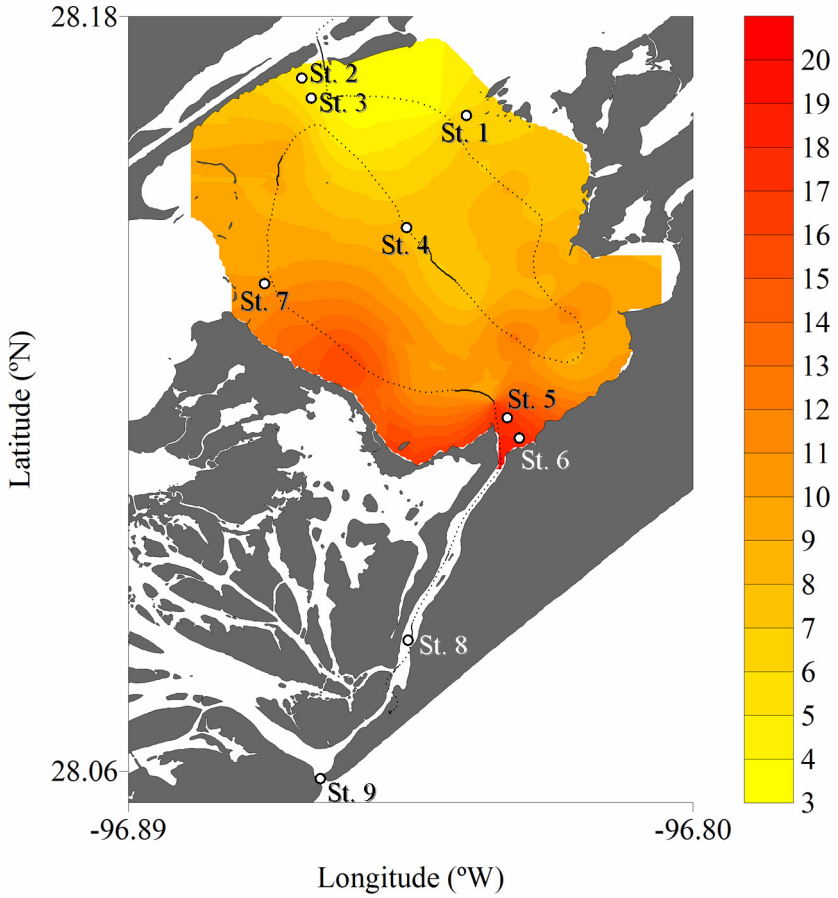


Fig. 14. Spatial interpolation of salinity for April 2005 in Mesquite Bay, Texas.

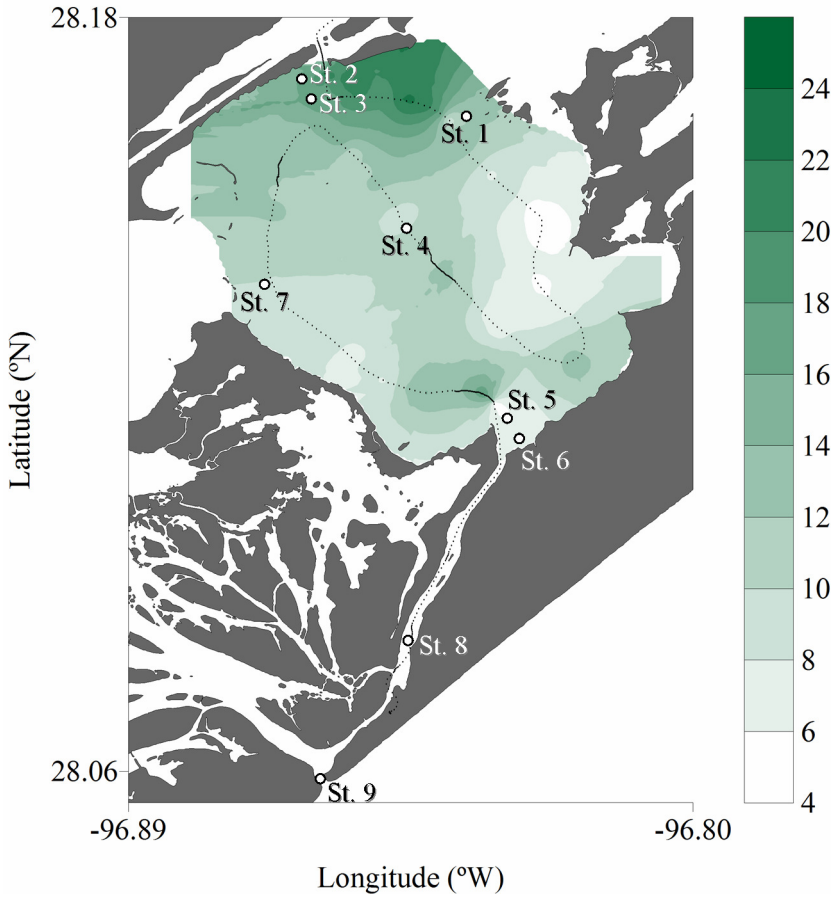


Fig. 15. Spatial interpolation of chlorophyll *a* for April 2005 in Mesquite Bay, Texas.

Ordination results for summer indicated a temporal trend with decreased spatial heterogeneity (Fig. 16). Slight spatial heterogeneity was evident for stations 8 and 9. During June 2005 various parameters were influential including: gross production (stations 2-9), respiration (1 and 5-9), salinity (stations 2 and 4-7), and chlorophyll *a* (station 2). Fixed station data indicated increases in gross production rates (excluding stations 4 and 5) and increases in respiration rates (excluding station 8) from May (Fig. 9

and Appendix C). Fixed station data and the spatial image for salinity indicated an increase in spatial heterogeneity of salinity levels (Fig. 4, 17, and Appendix B).

During July 2005 various parameters were influential including: gross production (stations 1, 5, 6, 8, and 9), respiration (stations 6, 8, and 9), secchi depth (stations 2-4 and 7), and salinity for stations 1, 4, and 5 (Fig. 16). Fixed station data indicated increases in gross production rates (excluding station 5), increases in respiration rates (excluding station 8), and decreases in secchi depth from June (Fig. 9 and 18, Appendices B and C). Fixed station data and the spatial image for salinity indicated a decrease in spatial heterogeneity of salinity levels with high salinity levels corresponding with stations 1, 4, and 5 (Fig. 19 and Appendices B and D).

During August 2005 various parameters were influential including: secchi depth (stations 1-7), salinity (stations 1-6), gross production and respiration (stations 8 and 9), and total ostracods for stations 8 and 9 (Fig 16). Fixed station data indicated increases from July in gross production rates and respiration rates with decreases in total ostracods biovolume for stations 8 and 9 (Fig. 9 and Appendix C). The data also indicates increases in secchi depth (excluding station 8) from July (Fig. 18 and Appendix B). Fixed station data and the spatial image for salinity indicated further decreases in spatial heterogeneity of salinity levels (Fig. 4 and 20 and Appendices B and D).

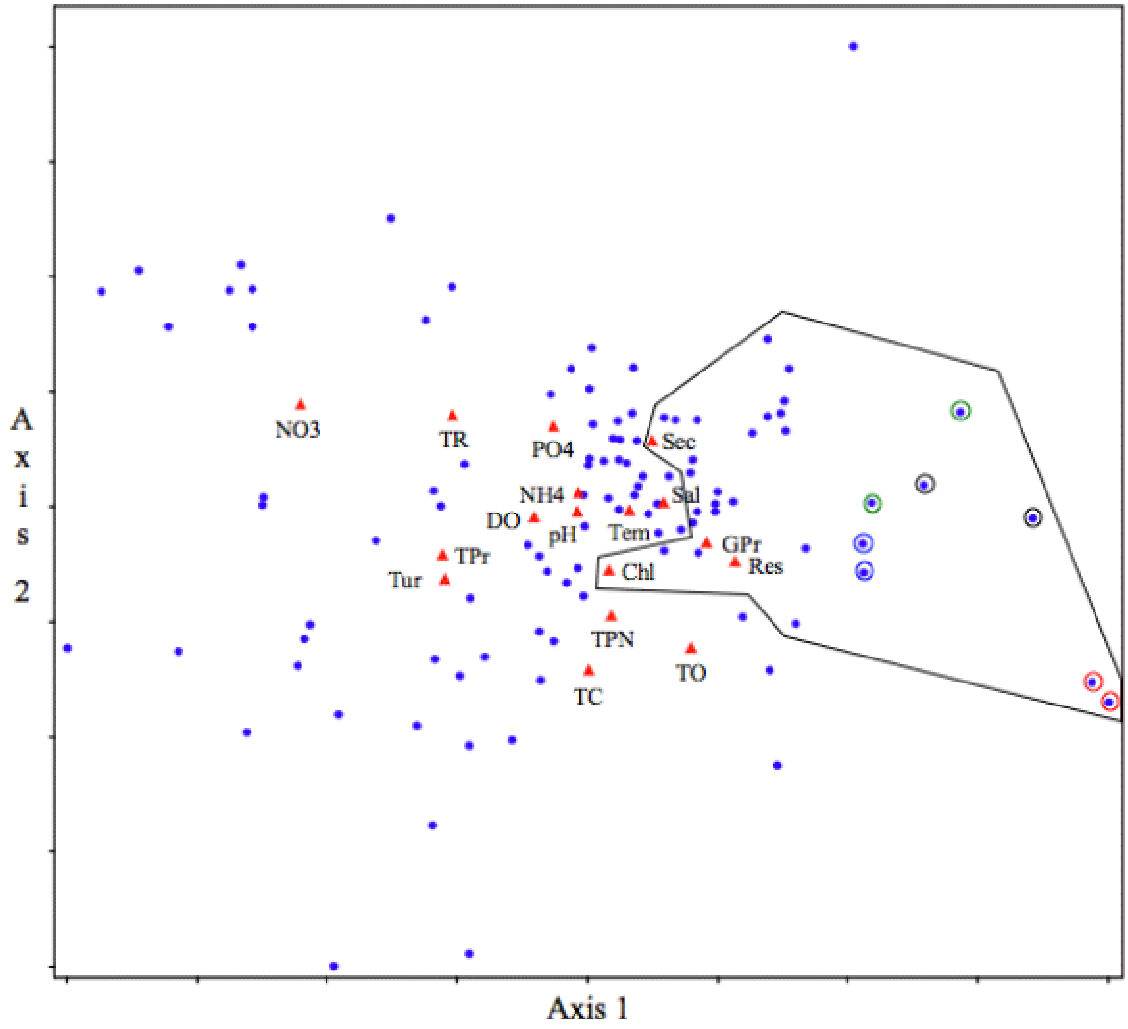


Fig. 16. Two-dimensional, non-metric, multidimensional ordination results for sampled parameters in Mesquite Bay, Texas for summer (June 2005 to August 2005) as indicated by the black line. Blue circles indicate station 8 and 9 ordinations for June 2005. Green circles indicate station 8 and 9 ordinations for July 2005. Red circles indicate station 8 and 9 ordinations for August 2005. Black circles indicate stations ordinations for spring 2005.

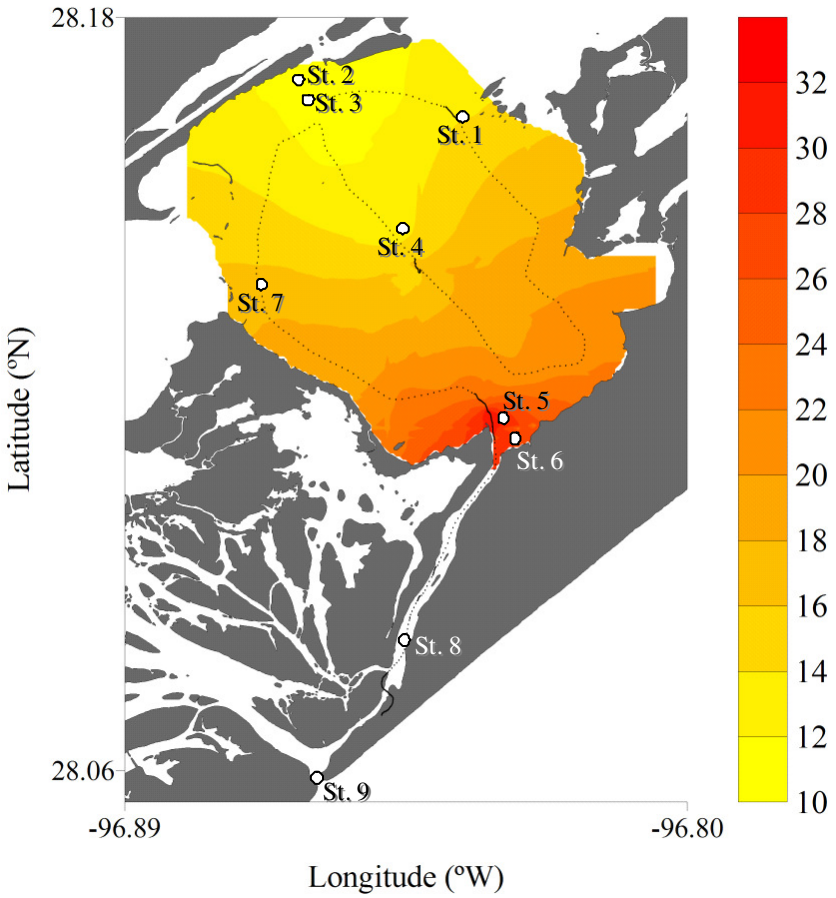


Fig. 17. Spatial interpolation of salinity for June 2005 in Mesquite Bay, Texas.

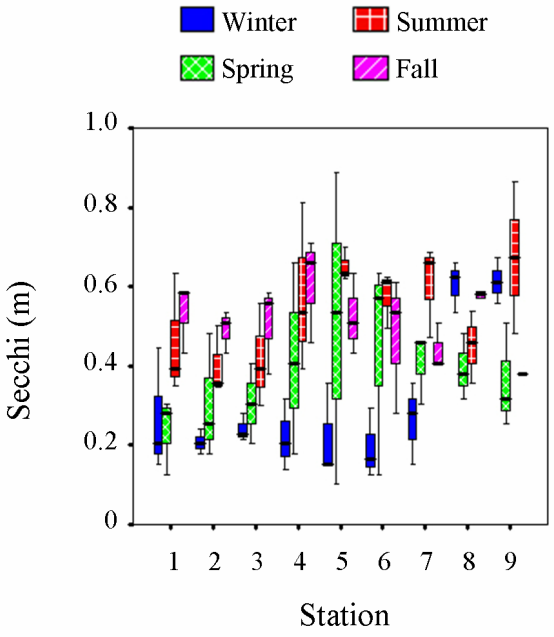


Fig. 18. Seasonal trends for stations 1-9 for secchi depth for Mesquite Bay Texas.

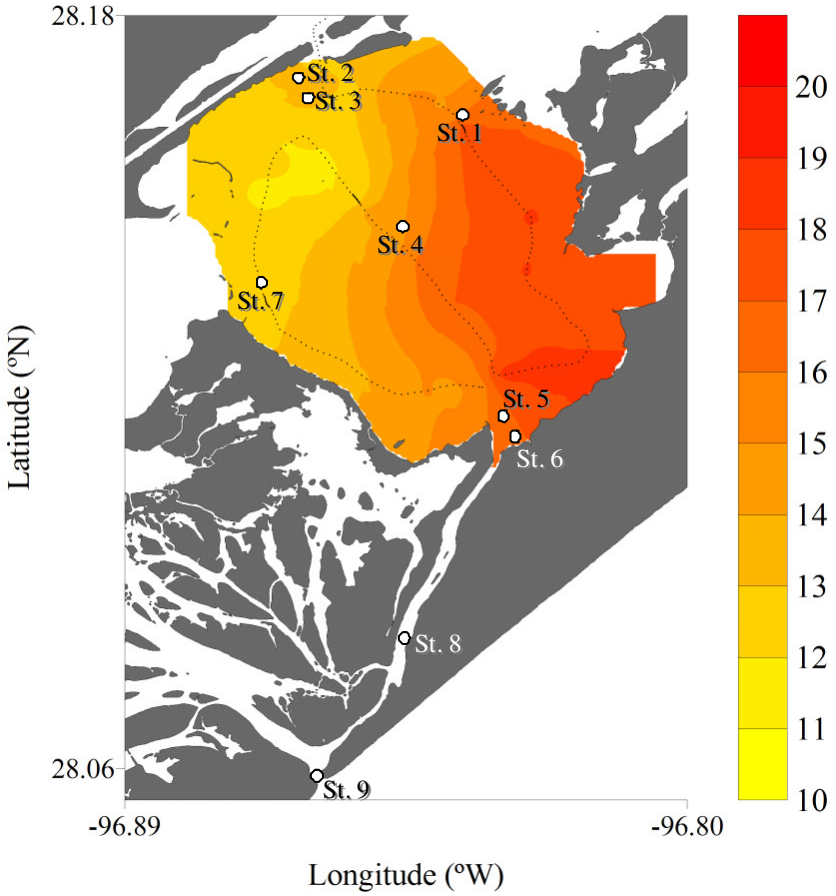


Fig. 19. Spatial interpolation of salinity for July 2005 in Mesquite Bay, Texas.

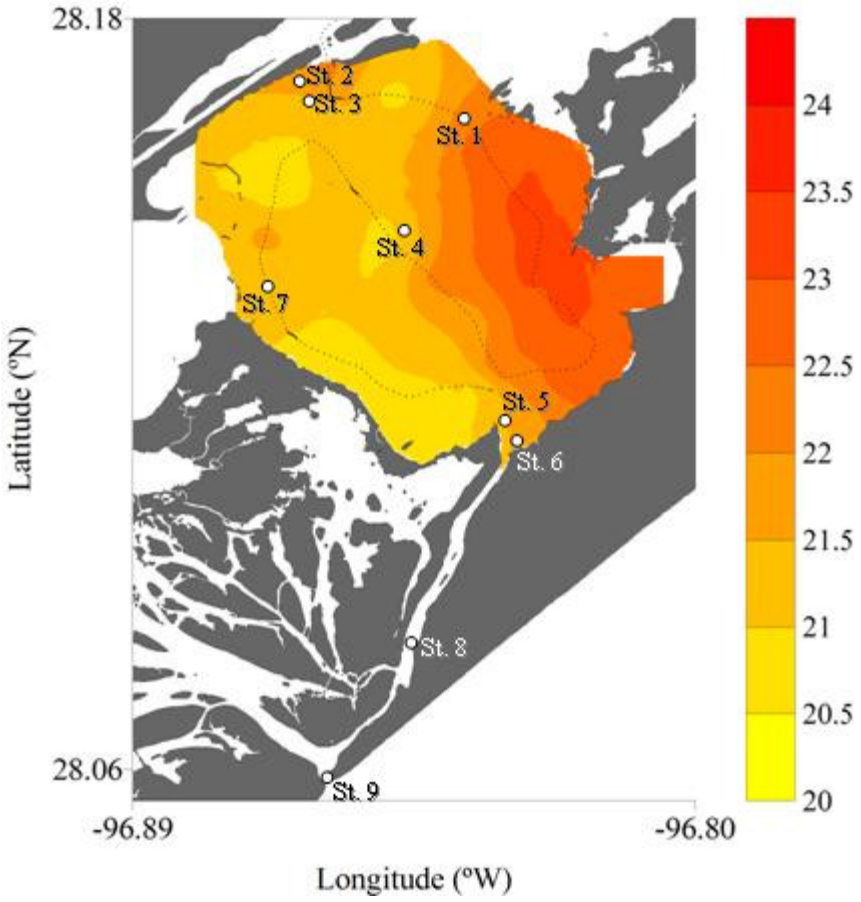


Fig. 20. Spatial interpolation of salinity for August 2005 in Mesquite Bay, Texas.

Ordination results for fall indicated a temporal trend with minimal spatial heterogeneity (Fig. 21). Multiple parameters were influential for September 2005 including: secchi depth (stations 1-4), water temperature (stations 5-7), NH_4^+ (stations 4, 6, and 7), and PO_4^{3-} (station 1). Fixed station data indicated increases for all aforementioned parameters at these stations (Fig. 9, 18, and 22 and Appendix B).

During October 2005 multiple parameters were influential including: secchi depth (stations 1, 4, 5, and 8), NH_4^+ (stations 5-7), and PO_4^{3-} for stations 2-4 (Fig. 21). Fixed station data shows decreases in secchi depth and increases in PO_4^{3-} for aforementioned parameters at these stations (Fig. 18 and 22 and Appendix B).

November 2004 indicated secchi depth (stations 1, 6, 8, and 9), PO_4^{3-} (stations 1-4), NH_4^+ (stations 5 and 7), salinity (stations 8 and 9), and respiration rates (station 6) as most influential (Fig. 21). Fixed station data indicated increased PO_4^{3-} concentrations, variable secchi depth, and lowest NH_4^+ concentrations (Figs. 9, 18, and 22, and Appendices B and C).

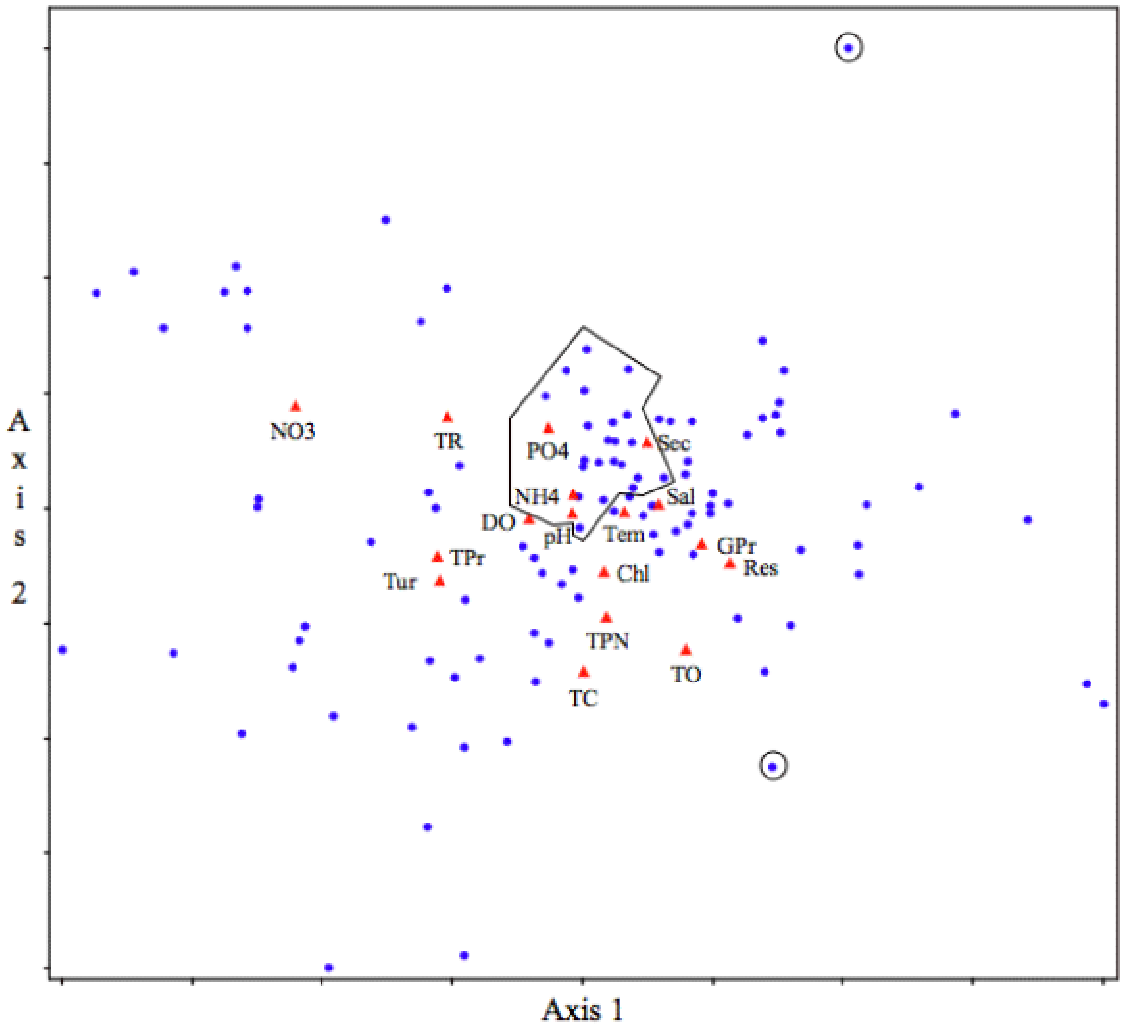


Fig. 21. Two-dimensional, non-metric, multidimensional ordination results for sampled parameters in Mesquite Bay, Texas for fall (September 2005 to November 2004) as indicated by the black lines. Black circles indicate station 6 (bottom circle) and station 8 (top circle) ordinations for October 2005.

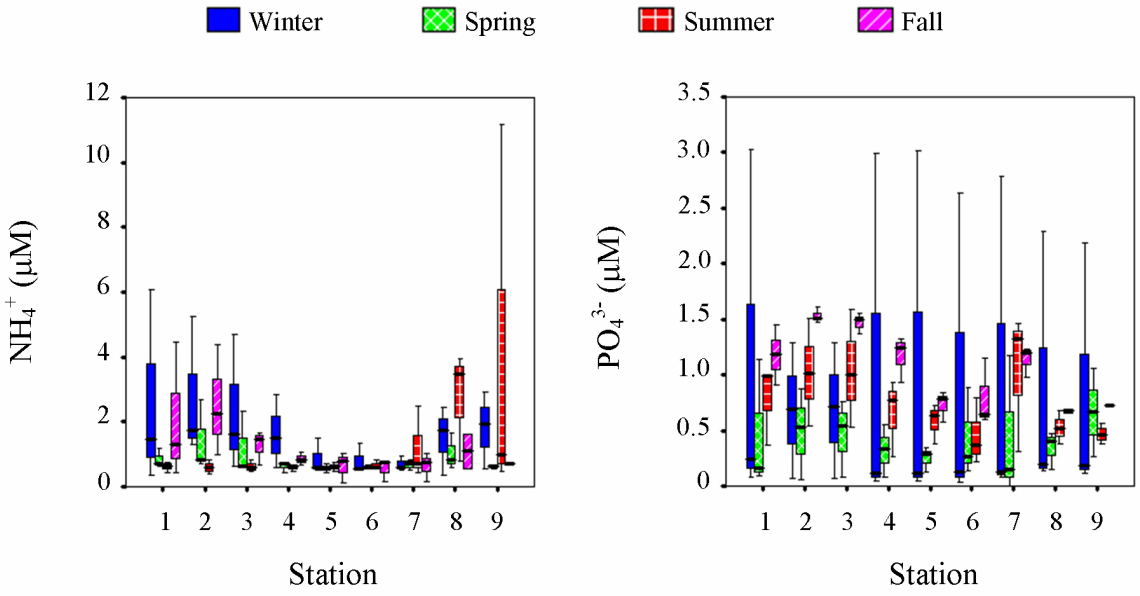


Fig. 22. Seasonal trends for stations 1-9 for NH_4^+ and PO_4^{3-} for Mesquite Bay Texas.

DISCUSSION

In this research, I explored the relationships between temporal and spatial trends in plankton communities and characterizations of the physicochemical environment. Mesquite Bay, Texas can be classified as a vertically homogenous estuary with trends in physical, chemical, spatial data for physicochemical parameters, and biological parameters providing evidence to suggest the influence of both temporal and spatial drivers as controlling these physical and biological components. However, trends in these system parameters indicate temporal drivers being more important than spatial drivers during the period sampled.

Importance of temporal drivers in Mesquite Bay

Temporal drivers have long been known to be influential in physical, chemical, and biological processes and under certain conditions can become the dominant controlling factor in system dynamics. Temporal drivers in estuarine ecosystems and Mesquite Bay, Texas include: water temperature, timing of freshwater inflows, seasonal wind direction, and food web interactions.

Water temperature

Water temperature exhibited a strong temporal trend increasing from winter through summer and decreasing again in fall for fixed station data and spatial maps (see Appendix B and F). Trends and ranges in temperature exhibited similar trends with bays systems in Texas, Florida, South Carolina, and Virginia where temperature exhibited

positive correlations with seasonal cycles in PAR (MacIntyre and Cullen 1996; Mortazavi et al. 2000; Phlips et al. 2002; White et al. 2004). Water temperature for fixed station data in Mesquite Bay exhibited negative correlations with chlorophyll *a* for stations 2-7 (0.16-0.53) and positive correlations for stations 1, 8, and 9 (0.14, 0.55, 0.61). These trends are opposite of the strong positive correlations of water temperature and chlorophyll *a* seen in the Murrells Inlet and North Inlet estuaries of South Carolina, characterized by a larger tidal range, ~ 1.37 m (White et al. 2004). However, sporadic correlations of water temperature and chlorophyll *a* were seen in Indian River lagoon in Florida where these deviations were hypothesized to be related to restricted water exchanges (residence time) and nutrient limitation as a function of decreased freshwater inflow (Phlips et al. 2002). Additionally, fixed station data for water temperature in Mesquite Bay exhibited positive correlations (0.41-0.69) with gross production for all stations (excluding station 7). These trends are concurrent with other systems throughout the U.S (including adjacent San Antonio Bay, Texas) with high rates of production during spring and late summer months (Mortazavi et al. 2000; Caffrey 2004). Gross production rates ranged from 0-2.44 g C m^{-2} d^{-1} (excluding stations 9) falling within previous estimates for San Antonio Bay, Caribbean, Gulf of Mexico, Mid-Atlantic, and North East estuaries of the U.S. (MacIntyre and Cullen 1996; Caffrey 2004). DO for Mesquite Bay ranged from 1.69 to 9.99 mg L^{-1} (see Appendix B). Trends in DO also exhibited a high negative correlation (0.81-0.95) with seasonal trends in water temperature, negative correlations with gross production (0.28-0.59) (excluding stations 2 and 7), and negative correlations with respiration (0.19-0.96) (excluding

station 2). Trends in DO for Mesquite Bay are similar to other studies in estuaries of Texas and other national estuarine research reserves (Wenner et al. 2004; Applebaum et al. 2005).

Timing of freshwater inflows

Salinity exhibited temporal trends increasing from winter and spring through summer and decreasing again in fall (see Appendix B). These trends do not coincide with historic 71-year inflow rates and seasonal precipitation during late spring and summer months in Texas. Studies in San Antonio Bay exhibited increased inflow levels during June and July and subsequent decreases in salinity levels (MacIntyre and Cullen 1996). Trends in inflow and salinity during the study can be attributed to higher than average inflow events from substantial rain events in Texas during the winter of 2004 (see Fig. 2). In addition, turbidity was highest during winter, decreased through summer, and increased again in fall (see Appendix B). Fixed station data for turbidity exhibited a negative correlation with salinity (0.38-0.59) excluding station 9, suggesting the influence of salinity on sediment flocculation, and negative correlation (0.57-0.92) with secchi depth suggesting light limitation as a function of turbidity and salinity induced sediment flocculation on biological processes. Similar relationships of turbidity and salinity have been seen in estuaries with open exchanges and restricted exchanges in England's Tweed Estuary and Florida's St. Lucie estuary (Doering 1996; Uncles and Stephens 1997). Additionally, slight to moderate negative correlations of gross production (0.26-0.61), excluding stations 2 and 7, and respiration rates (0.29-0.68),

excluding station 2, with turbidity suggest light limitation of these processes. Studies in estuaries of San Antonio Bay in Texas, Estero de Punta Banda in Baja California, Westerschelde Estuary in the Netherlands, and Gironde in France have shown similar correlations of turbidity and gross production (Kromkamp et al. 1995; MacIntyre and Cullen 1996; Irigoien and Castel 1997; Montes-Hugo et al. 2004). Nutrient concentrations also exhibited a temporal trend being highest in winter, decreasing in spring and summer, and increasing again in the fall coinciding with increased freshwater inflow rates from aforementioned seasonal precipitation events (see Appendix B). Combinations of various inorganic nutrients exhibited slight to moderate positive and negative correlations with phytoplankton biomass indicating the importance of ratios of limiting nutrients on timing and magnitude of phytoplankton biomass. These trends are similar for various estuaries in Texas, Florida, South Carolina, and Virginia where inflow events caused increase in various organic and inorganic nutrients with variable affects on phytoplankton dynamics, abundance, and biomass (MacIntyre and Cullen 1996; Sin et al. 1999; Mortazavi et al. 2000; Phlips et al. 2002; White et al. 2004; Buyukates and Roelke 2005b). Spatial maps for salinity, FDOM, turbidity, and chlorophyll *a* provide additional supporting evidence for temporal trends in system parameters as a function of the timing of freshwater inflows.

Seasonal wind direction

Fixed station data for turbidity exhibited a strong temporal trend decreasing from winter through summer and increasing again in fall (Appendix B). These trends

coincide with seasonal wind direction and magnitude with strong northerly winds during late fall and winter and calmer south easterly winds during late spring, summer and early fall. Similar trends in turbidity were experience in various water bodies of the Louisiana Barataria Basin, where critical winds speeds > 4 m s^{-1} for inducing sediment resuspension were achieved 80% of the time during winter months (Booth et al. 2000). Wind speed for Mesquite Bay was > 4.4 m s^{-1} for all sampling dates (see Table 1), thus achieved similar critical wind speed velocities for sediment resuspension. Spatial maps for turbidity reaffirm the influence of wind magnitude and direction on temporal trends in turbidity with highest system wide turbidity levels during winter and spring months (Appendix D). These trends coupled with lower salinity levels and subsequent decreased sediment flocculation lead to the persistence of higher turbidity levels and thus light limitation on gross production and respiration rates as previously mentioned. These trends explain variances from theorized trends in graphical representations of 12 hour, 24 hour, 3 day, 7 day, and 14 day wind speed and fixed station turbidity levels in relation to fetch (Figure 7).

Food web interactions

Zooplankton community biovolume and composition exhibited a seasonal trend with highest biovolume during spring and summer compared to fall and winter, excluding rotifers (Appendix C). These trends were similar to temporal dynamics of zooplankton in Westerschelde, Neuse River, and Nueces Delta (Mallin 1991; Soetaert and Rijswijk 1993; Buyukates and Roelke 2005b). Total copepod biovolume exhibited positive

correlations (0.09-0.26 for stations 2-4, and 0.42-0.84 for stations 1 and 5-9) with phytoplankton biomass suggesting bottom up control on total copepod biovolume. Other zooplankton taxonomic groups exhibited variable positive and negative correlations with phytoplankton biomass and other taxonomic groups of zooplankton indicating other influential factors. Various species of protozoans are known to prey on bacterial populations in marine environments (Rassoulzadegan and Sheldon 1986). Total rotifer bio-volume consisted of various species of the genera *Bdelloidea*, *Gastropus*, *Euchlanis*, *Keratella*, *Synchaeta*, *Polyarthra*, and *Brachionus*. These species are characteristic of benthic and pelagic habitats and selective feeding behaviors and could thus account for the seasonal variability in biovolume and correlations with other zooplankton taxonomic groups. Additionally ostarcods, polychaetes, and nematodes are known to be detritivores with ostracods and nematodes occasionally can exhibit opportunistic scavenging and predation (Jensen 1987; Vannier et al. 1998). Finally, predation on these taxonomic groups by zooplanktivourous plankton and itchyofauana could exhibit top down control.

Importance of spatial drivers in Mesquite Bay

All physical, chemical, physicochemical, and biological parameters indicated some spatial heterogeneity within Mesquite Bay. Stations 2, 3, 8, and 9 exhibited differences from other stations in these parameters during the study. These suggest spatial drivers influencing these stations as well as spatial trends in system-wide physiochemical water parameters. Spatial drivers in estuarine ecosystems and Mesquite Bay, Texas include:

water exchange at stations 2 and 3 through Bludworth Island Pass, water exchange through Cedar Bayou pass at stations 8 and 9, inflow magnitude, and wind direction and magnitude.

Water exchange through Bludworth Island Pass and Cedar Bayou

Stations 2 and 3 (Bludworth Island Pass) exhibited differences from all other stations in the following parameters: salinity, DO, pH, inorganic nutrients, phytoplankton biomass, production and respiration rates, and zooplankton biovolume. Spatial maps for salinity, FDOM, and chlorophyll *a* provide supporting evidence for these trends and support the importance of exchange of water with the GIWW.

Stations 8 and 9 (Cedar Bayou) also exhibited differences form all other stations in the following parameters: salinity, DO, pH, inorganic nutrients, phytoplankton biomass, production and respiration rates, and zooplankton biovolume and composition. Correlations with data arrays from stations 5, 6, 8, and 9 show no significant correlations between stations 5 and 6 against stations 8 and 9. This could be due to net flow through Cedar Bayou being towards the Gulf of Mexico and presence of saltmarsh habitat lining the channel.

Magnitude of freshwater inflow

The magnitude of freshwater inflow rates into Mesquite Bay through San Antonio Bay created spatial heterogeneity in salinity, inorganic nutrient concentrations, and FDOM. During maximum river inflow periods salinity exhibited minimal spatial

heterogeneity between stations (Appendices B and D). Under intermediate inflow levels, during late winter and early spring, spatial heterogeneity was more pronounced and decreased under lower than 71-year average inflow rates during late summer and early fall (Appendices B and D). This trend in spatial heterogeneity was confirmed by spatial maps for salinity (Appendix D). Additionally, spatial heterogeneity was evident under intermediate inflow levels for inorganic nutrient concentrations. Stations 1-4 experienced a second spike under a small magnitude inflow event during February 2005 suggesting the importance of inflow magnitude spatial heterogeneity of inorganic nutrients. Inorganic nutrients concentrations for Mesquite Bay ranged from: 0.70-38.36 μM for NO_3^- plus NO_2^-, 0.10 to 11.15 μM for NH_4^+, and 0.00 to 3.03 μM for PO_4^{3-}. These concentrations are slightly lower than reported concentrations in San Antonio Bay, Texas but higher than estuaries in the Lower Nueces Delta (excluding PO_4^{3-}) in Texas, and Murrells and North Inlet estuaries in South Carolina (MacIntyre and Cullen 1996; White et al. 2004; Buyukates and Roelke 2005b). As previously mentioned, NO_3^- plus NO_2^- exhibited negative correlations for all stations (excluding station 8) with salinity and positive correlations with inflow rate for all stations indicating freshwater inflow as a factor affecting concentrations of NO_3^- plus NO_2^-. These correlations with salinity and inflow rate were not seen with other inorganic nutrients for fixed station data suggesting other influential factors. Spatial maps for salinity and FDOM further support the influence of magnitude of freshwater inflows on spatial heterogeneity of FDOM and inorganic nutrient concentrations.

Wind direction and magnitude

Wind direction and magnitude created spatial heterogeneity in turbidity for fixed station data, and spatial maps of turbidity and chlorophyll *a*. Comparison of fixed station data indicated spatial trends were evident across stations 2, 3, 5, 6, 8, and 9. Turbidity was higher during the winter months for stations 5 and 6 when northerly winds were present with stations 2, 3, 8, and 9 exhibiting higher turbidity values during the remainder of the year when southeasterly winds were present. These trends were also seen in spatial maps for turbidity providing partial evidence of spatial heterogeneity due to wind magnitude and direction (see Appendix D). These trends indicate the partial influence of fetch on spatial heterogeneity in turbidity. Similar trends were seen in various portions of the Barataria Basin of Louisiana where fetch in relation to wind direction determine the spatial percentages of sediment resuspension (Booth et al. 2000). Additionally spatial maps and data for turbidity and chlorophyll *a* for various months indicate possible benthic macroalgae resuspension from benthic sediments. Spatial data for turbidity and chlorophyll *a* exhibited negative correlations during February, April, and September 2005 (0.55, 0.70, 0.54 respectively). Additionally, fixed station data for turbidity and chlorophyll *a* exhibited a positive correlation (0.22-0.30 for stations 1 and 2, and 0.41-0.76 for stations 3-9). These trends suggest the influence of benthic microalgal contribution to chlorophyll *a* concentrations and possible contribution to primary production. Additionally, seasonal fixed station data for wind direction and chlorophyll *a* exhibited a minor negative correlation (0.14-0.38) for stations 1-7. This would suggest the influence of wind direction on spatial heterogeneity of chlorophyll *a*.

CONCLUSIONS

System parameters for Mesquite Bay, Texas indicate the importance of temporal drivers in controlling system dynamics. All parameters for fixed stations and dataflow data exhibited temporal trends. These temporal trends indicate the importance of temperature, timing of freshwater inflows, seasonal wind direction and magnitude, and food web interactions influencing phytoplankton biomass and zooplankton community biovolume and composition.

Temporal trends in water temperature did not affect phytoplankton biomass but determined rates of gross production and respiration, which in turn affected dissolved oxygen levels throughout the system. Timing of the large freshwater inflow during winter combined with high northerly winds in winter and early spring led to the persistence of system wide higher turbidity levels leading to decreases in secchi depth and light limitation of gross production and respiration rates for interior stations. Temporal trends in zooplankton taxonomic group biovolume revealed limited interactions, with total copepod biovolume exhibiting bottom up control by phytoplankton biomass for all stations with remaining taxonomic groups exhibiting variable relationships with phytoplankton biomass and inorganic nutrients.

Spatial drivers exhibited less influence on fixed station and dataflow parameters. Spatial trends indicated the importance of water exchange at stations 2 and 3 through Bludworth Island Pass, water exchange through Cedar Bayou pass at stations 8 and 9, inflow magnitude, and wind direction and magnitude.

Water exchange through Bludworth Island pass affected all parameters but exhibited only localized influence on spatial heterogeneity. Water exchange through Cedar Bayou affected all parameters at stations 8 and 9 with some evidence of influence on spatial heterogeneity at stations 5 and 6 in spatial data possibly influenced by spring, neap, and secular tides.

Intermediate inflow magnitude created spatial heterogeneity in salinity and concentrations of NO_3^- plus NO_2^- revealing other influential factors determining concentrations for other inorganic nutrients. Additionally, stratification as a result of inflow magnitude was only seen in salinity at stations 5 and 6 under intermediate inflow magnitude suggesting a vertically homogenous water column.

Wind direction and magnitude indicated the influence of fetch on spatial heterogeneity in turbidity with localized benthic microalgal contribution to chlorophyll *a* concentrations and possible contribution to primary production as a function of wind direction.

Spatial trends were less in magnitude and affected less fixed station and spatial data parameters. Three-dimensional station ordination plots indicated sporadic localized spatial heterogeneity with a more pronounced temporal trend affecting system parameters indicating temperature, salinity as a function of inflow timing, and seasonal wind direction affecting primary production and zooplankton community composition and abundance.

The issue of reopening Cedar Bayou pass has been the focus of numerous organizations at the civilian, state, federal, and academic levels. Currently civilian

entities have obtained a permit to dredge and are seeking funding with the intent of improving water exchange and thus water quality and migration routes for various species of macrofauna. The effects of dredging tidal passes are a highly debated topic in Texas, United States, and the world. Currently research has focused on hydrological effects of tidal exchanges in systems with relatively larger tidal passes and deeper estuarine systems with major freshwater tributaries as well as shallow estuaries with no freshwater inflow sources. These studies often overlook smaller, shallower systems with ephemeral tidal passes and minimal freshwater inflows. This study characterized the spatial and temporal effects of reduced tidal exchanges and freshwater inflows on structure and function of physicochemical, and biological parameters. This data will provide a baseline to determine the effects of dredging of small, bar built, micro tidal estuaries with reduced tidal exchanges and freshwater inflows in Texas, United States, and the world.

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APPENDIX A

Non-metric multidimensional scaling (PC-ORD, v.5) data arrays structure for determination of best statistical significance across all parameters:

- Salinity, Temperature, pH, DO, Turbidity, Secchi, NO_3^- + NO_2^-, NH_4^+, PO_4^{3-}, Chlorophyll *a*, Gross Productivity, and Respiration, Total Protozoans, Total Rotifers, Total Ostracods, Total Copepods, and Total Polycheates/Nematodes.

APPENDIX B

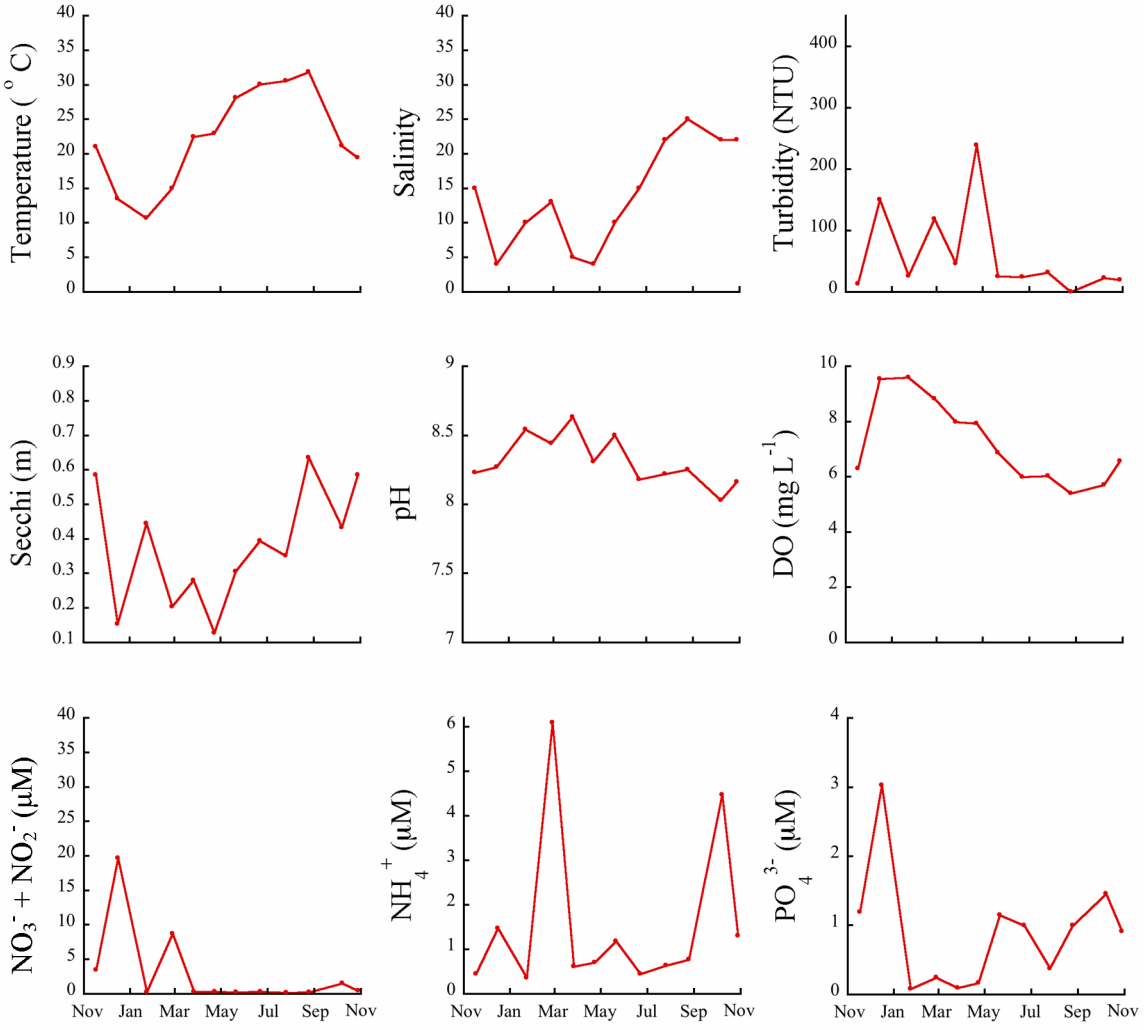

Fig. B-1. Station 1 physical and chemical parameters for Mesquite Bay, Texas (November 2004 to November 2005).

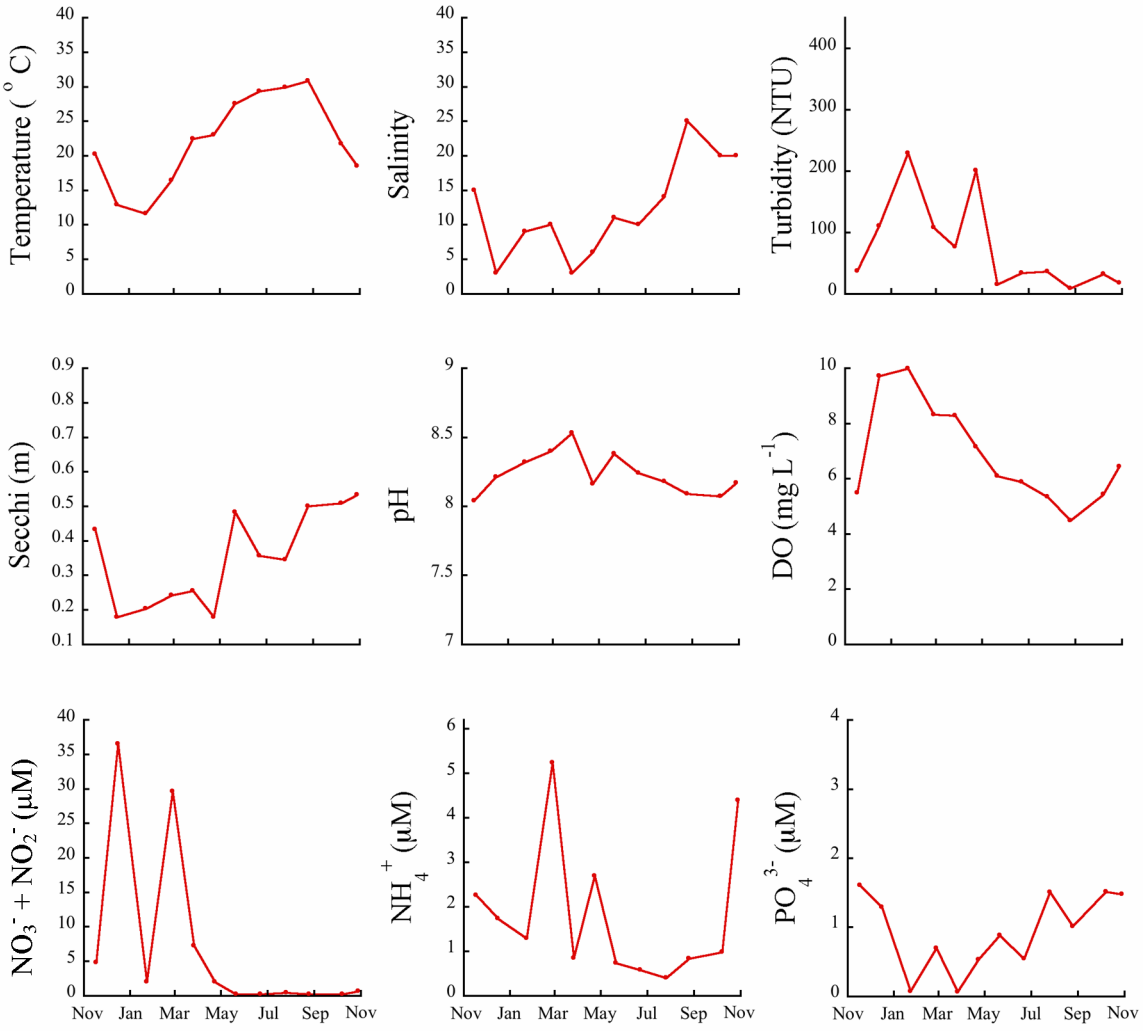

Fig. B-2. Station 2 physical and chemical parameters for Mesquite Bay, Texas (November 2004 to November 2005).

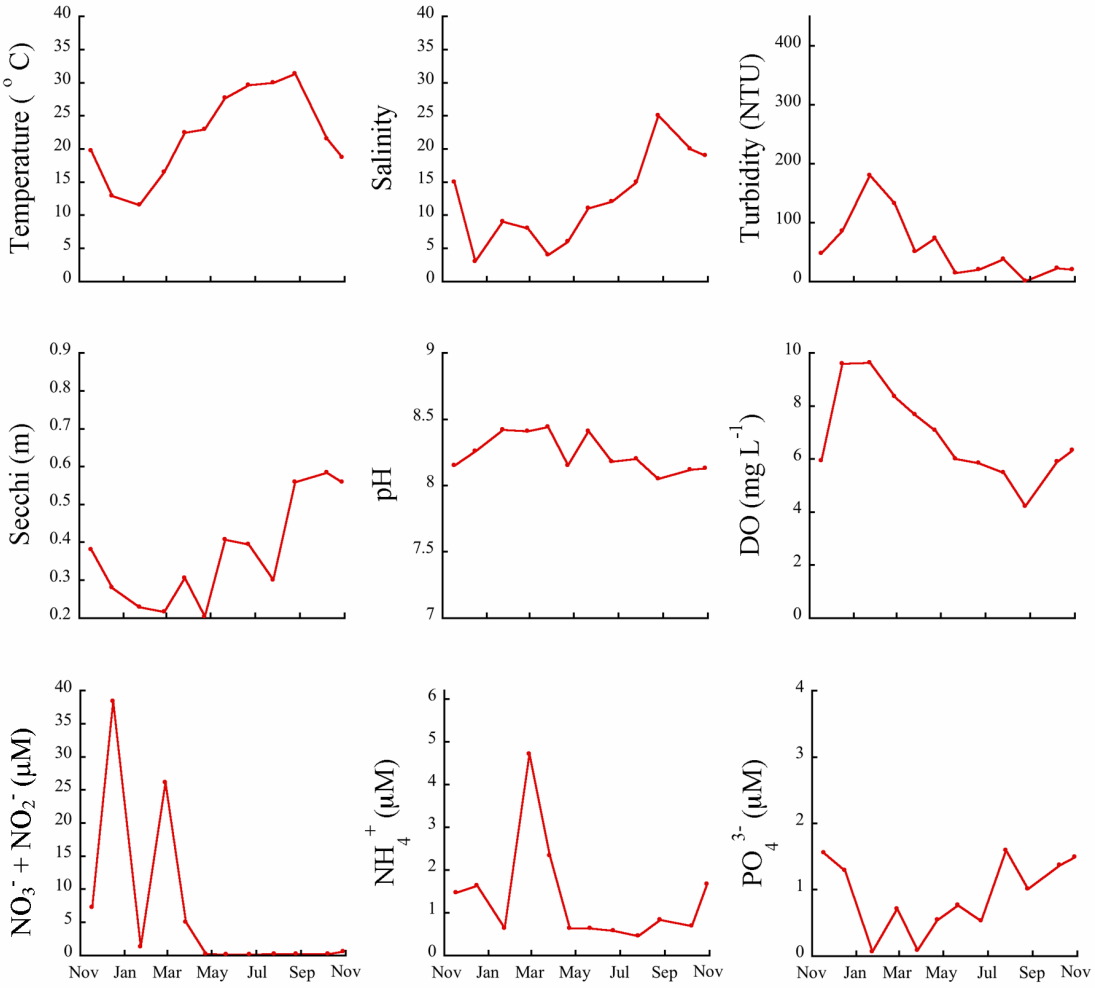

Fig. B-3. Station 3 physical and chemical parameters for Mesquite Bay, Texas (November 2004 to November 2005).

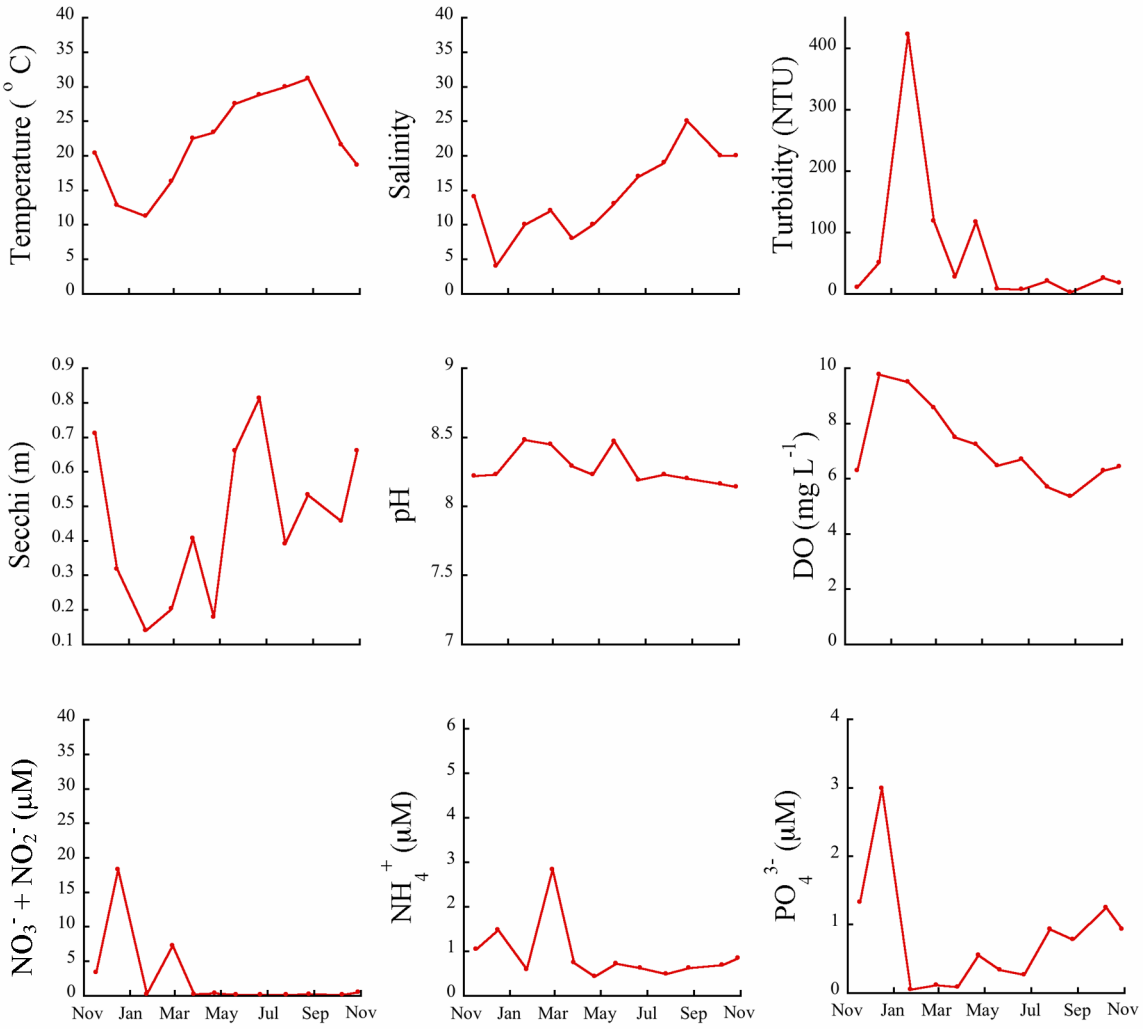

Fig. B-4. Station 4 physical and chemical parameters for Mesquite Bay, Texas (November 2004 to November 2005).

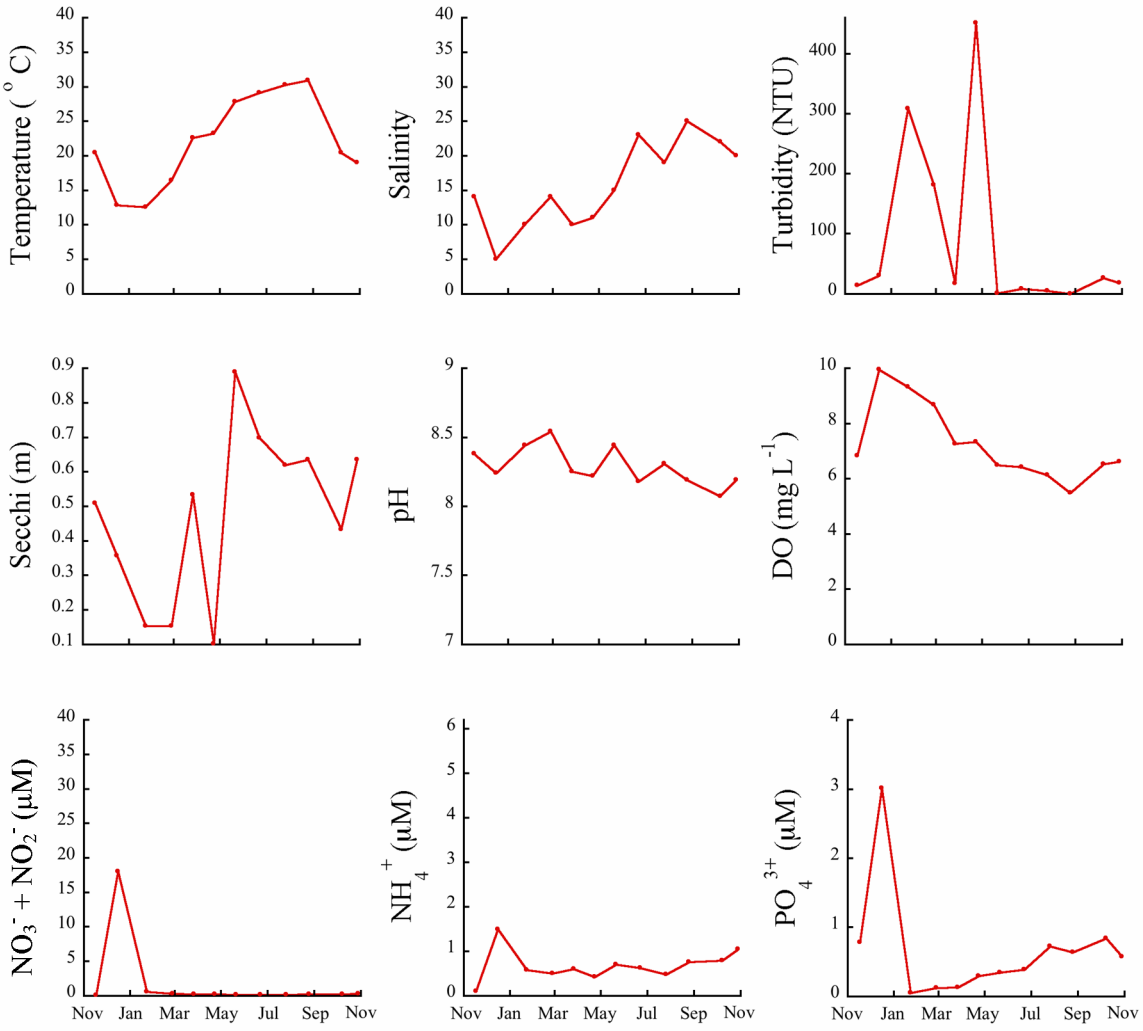

Fig. B-5. Station 5 physical and chemical parameters for Mesquite Bay, Texas (November 2004 to November 2005).

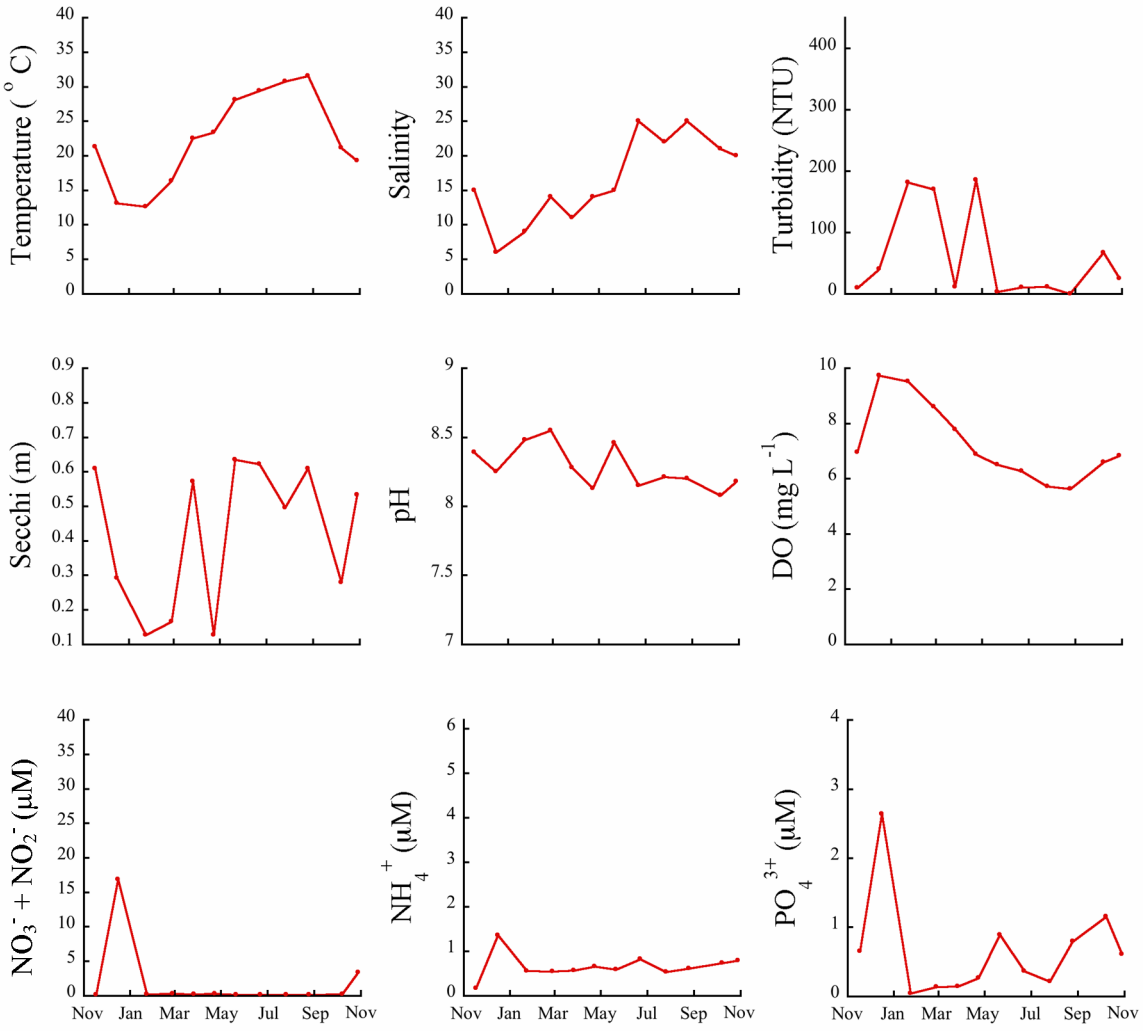

Fig. B-6. Station 6 physical and chemical parameters for Mesquite Bay, Texas (November 2004 to November 2005).

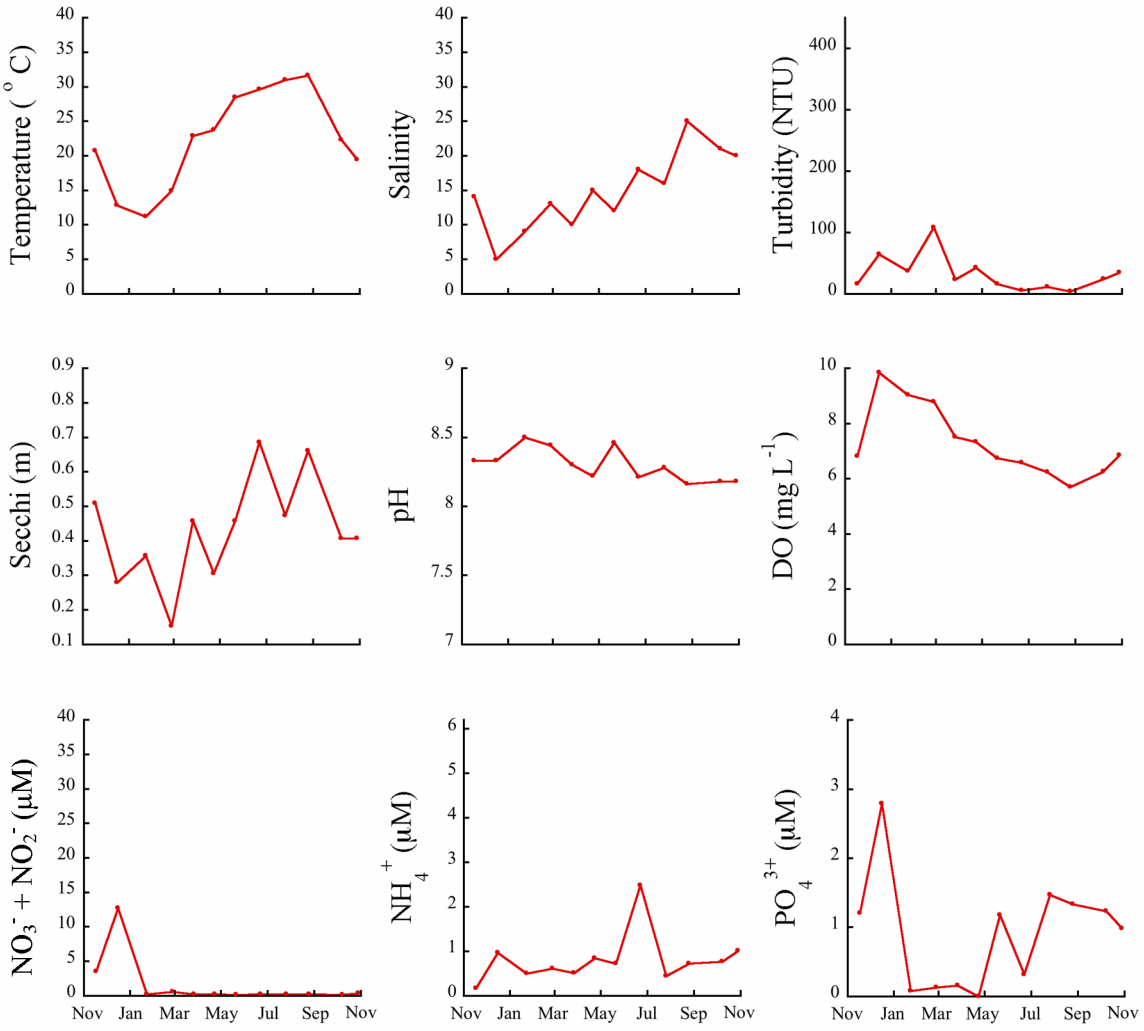

Fig. B-7. Station 7 physical and chemical parameters for Mesquite Bay, Texas (November 2004 to November 2005).

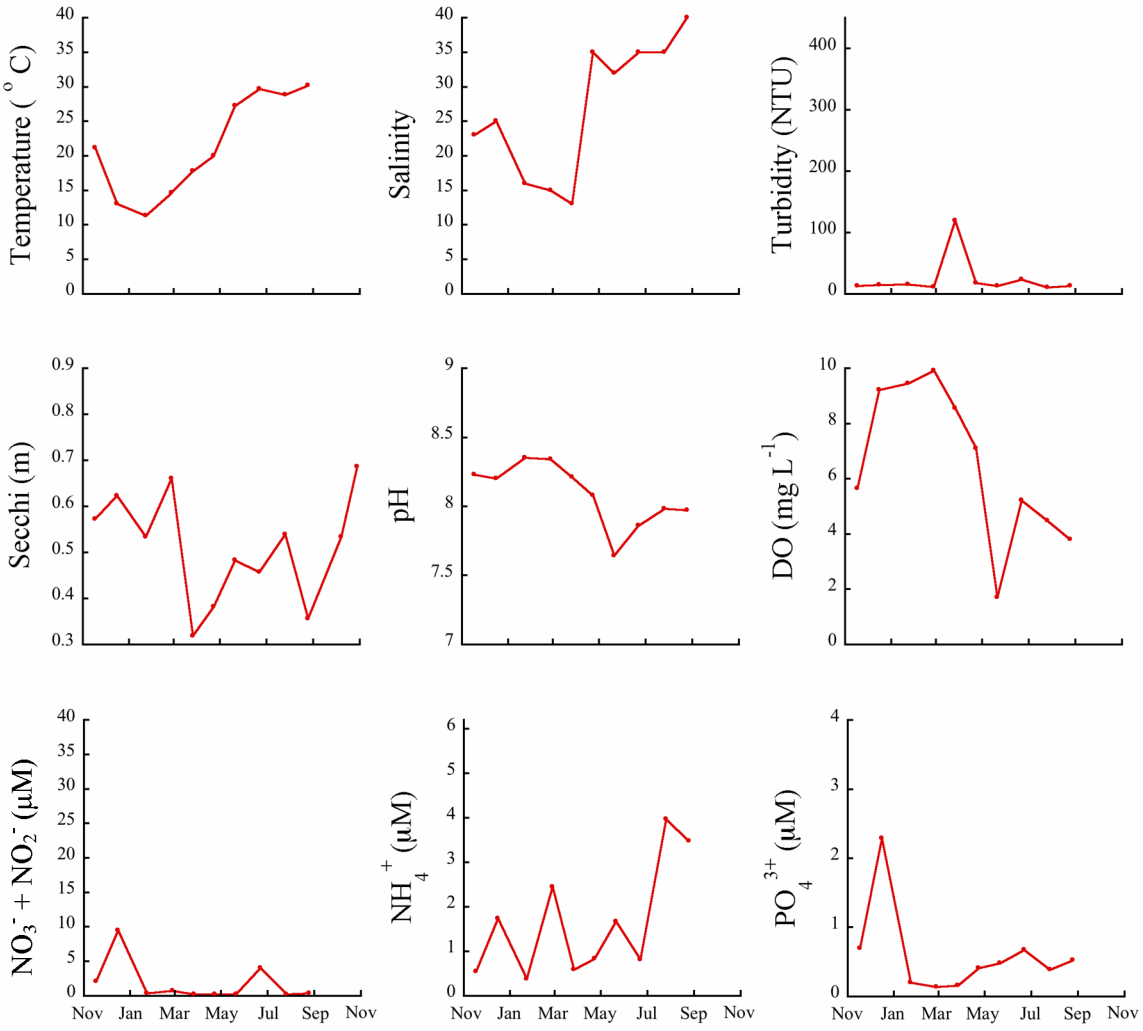

Fig. B-8. Station 8 physical and chemical parameters for Mesquite Bay, Texas (November 2004 to November 2005).

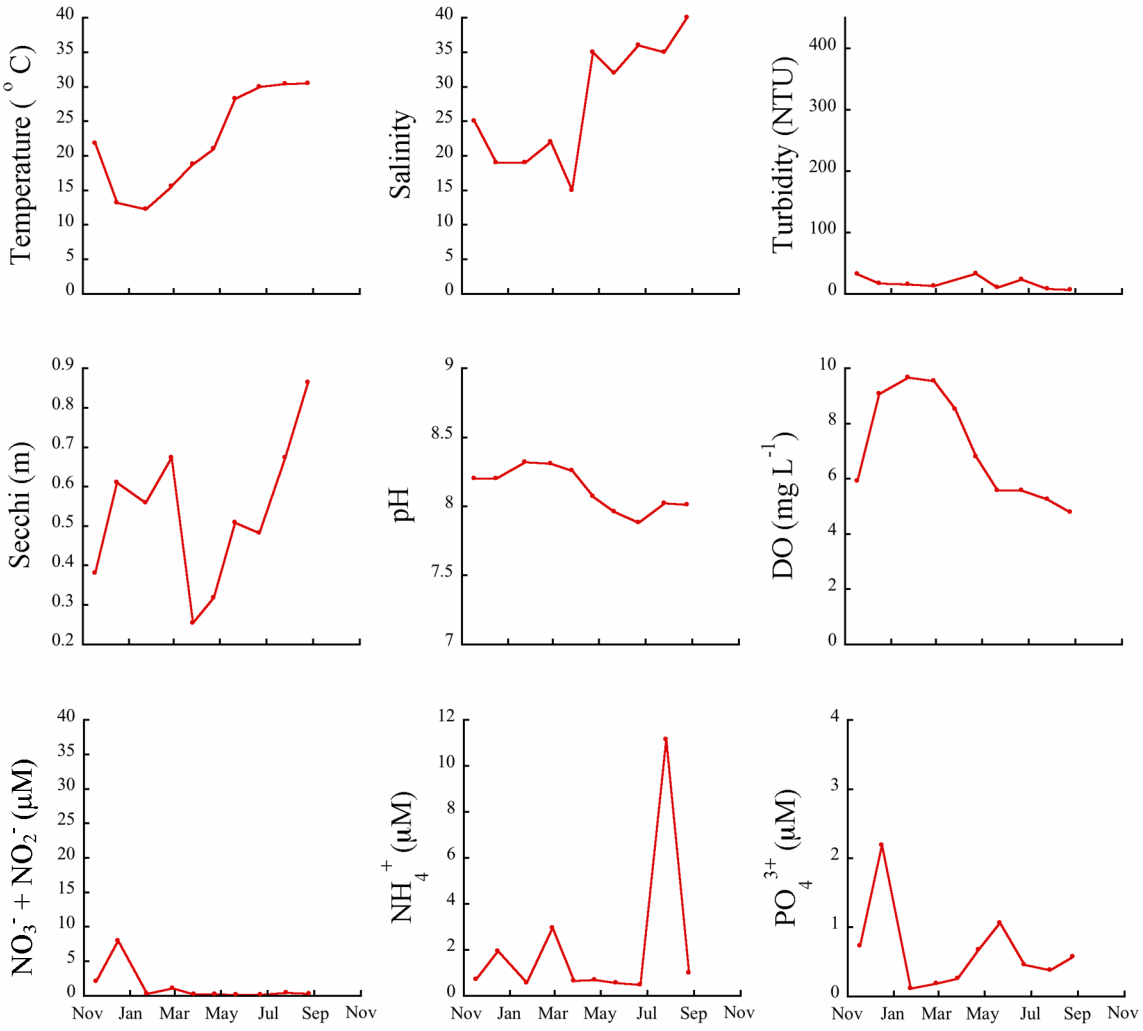

Fig. B-9. Station 9 physical and chemical parameters for Mesquite Bay, Texas (November 2004 to November 2005).

APPENDIX C

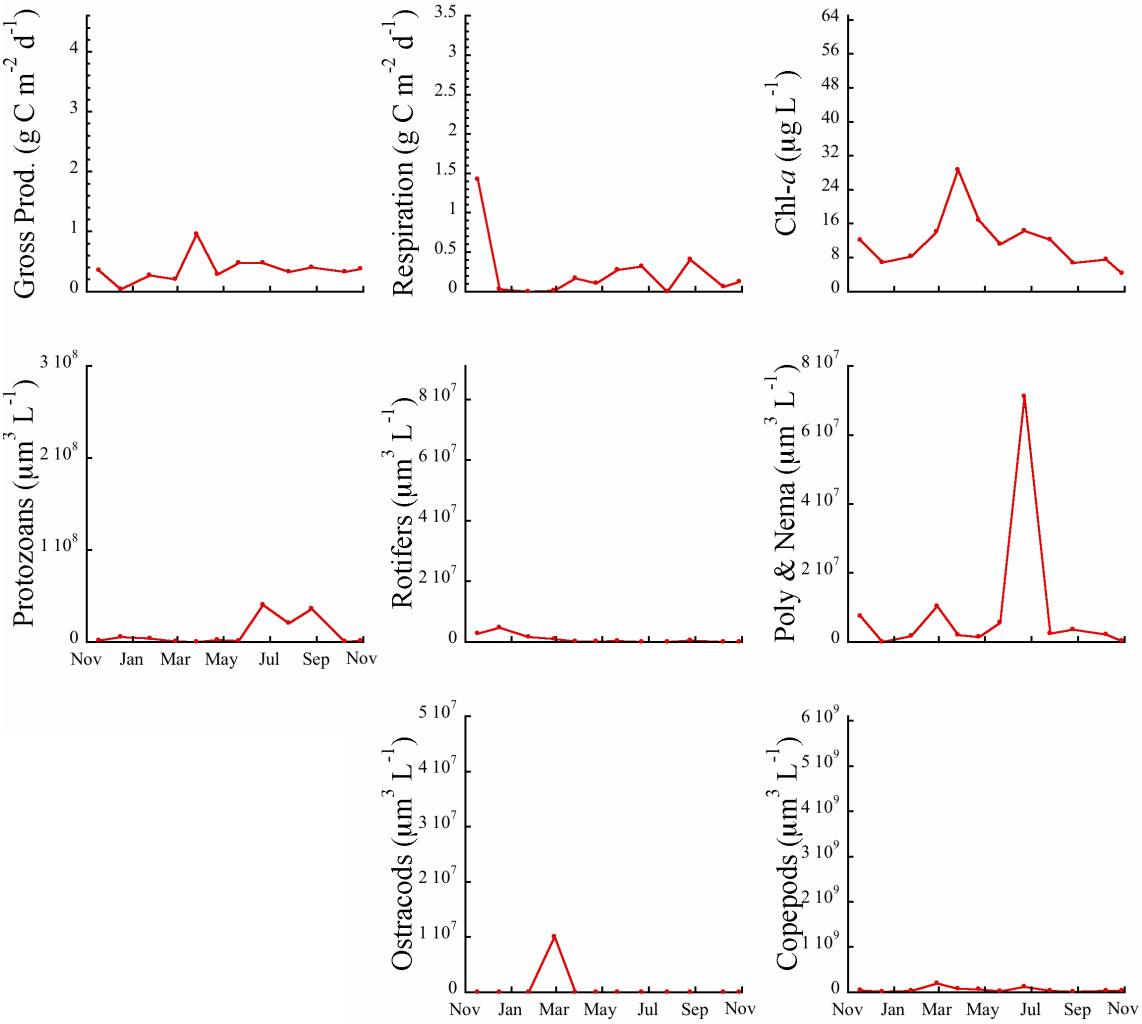

Fig. C-1. Station 1 biological parameters for Mesquite Bay, Texas (November 2004 to November 2005).

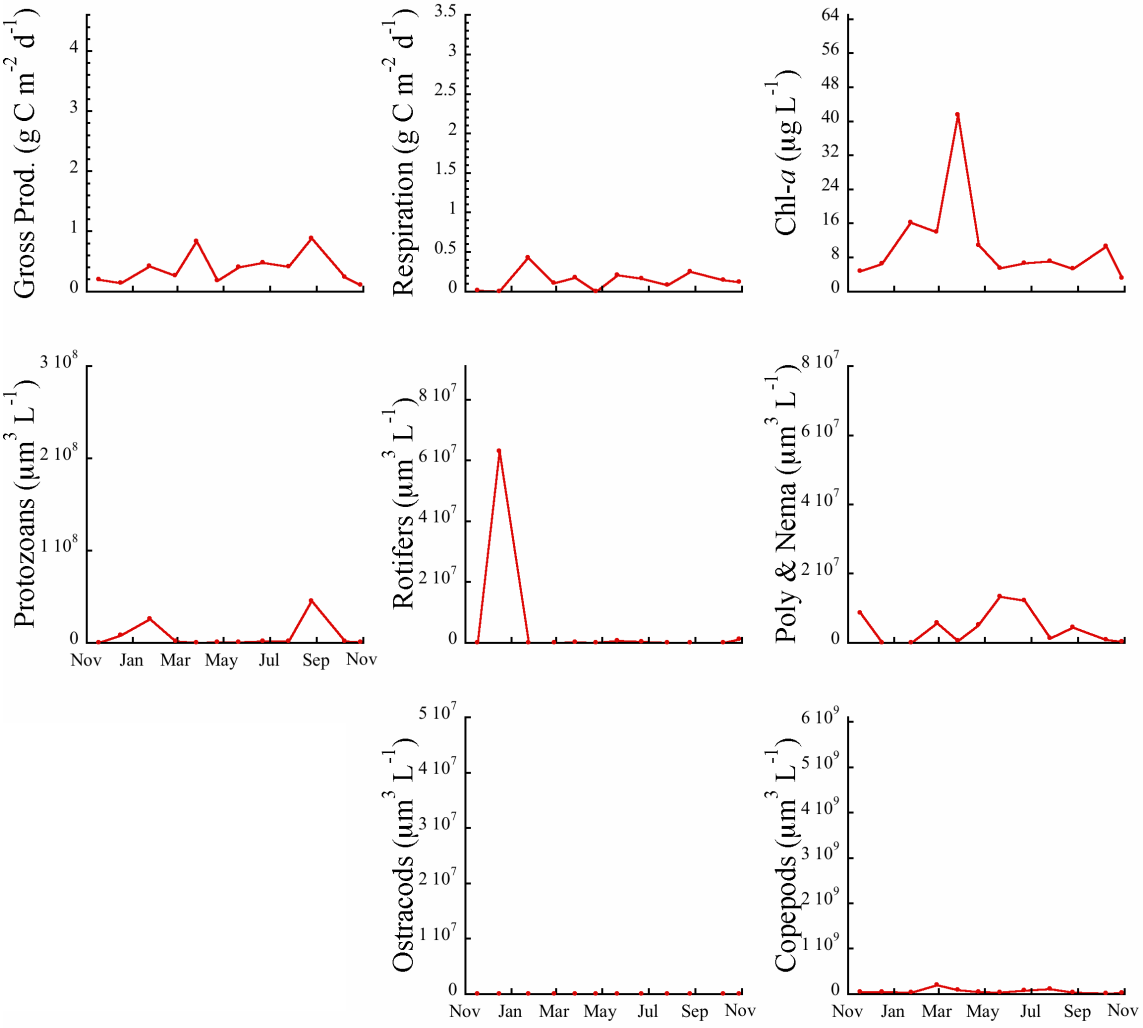

Fig. C-2. Station 2 biological parameters for Mesquite Bay, Texas (November 2004 to November 2005).

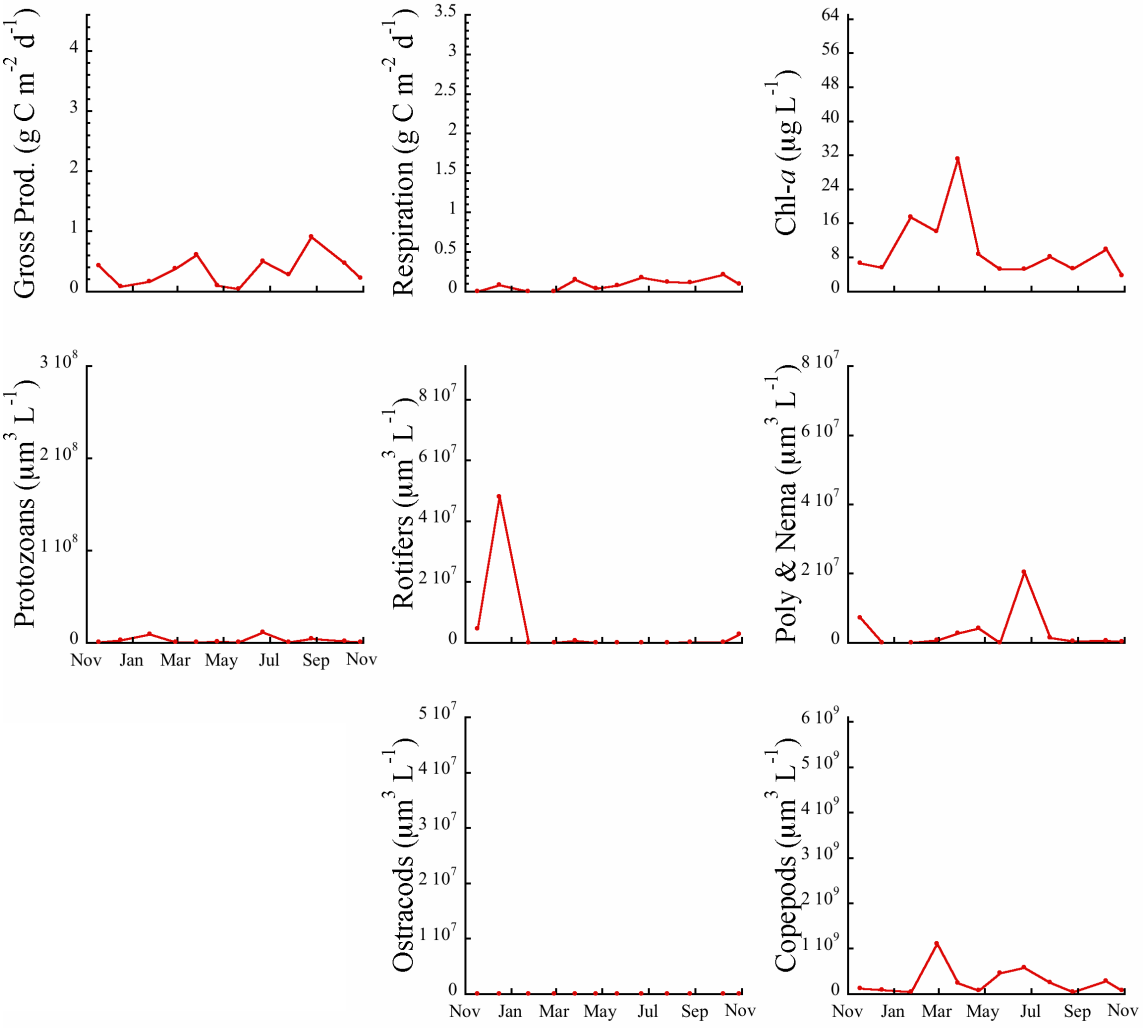

Fig. C-3. Station 3 biological parameters for Mesquite Bay, Texas (November 2004 to November 2005).

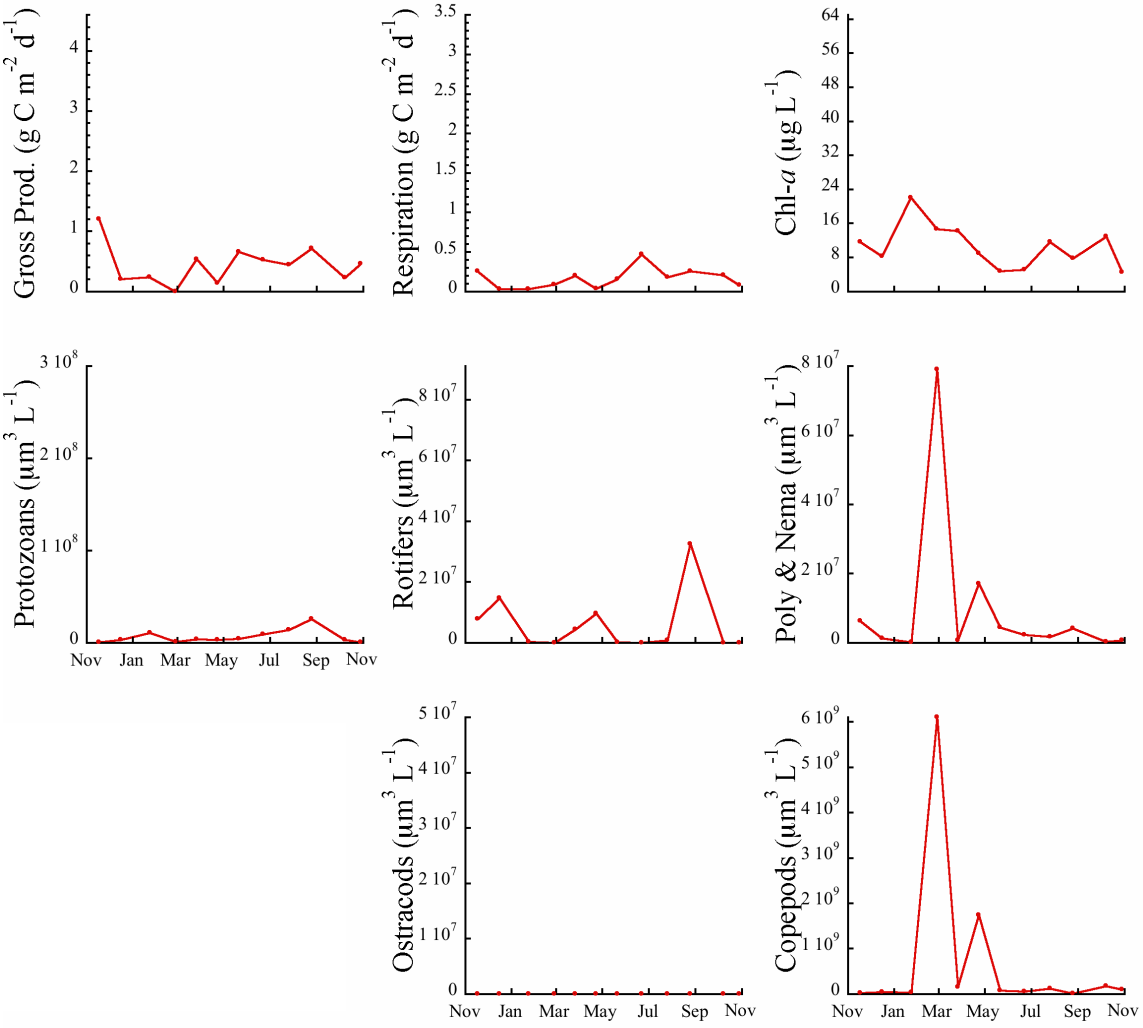

Fig. C-4. Station 4 biological parameters for Mesquite Bay, Texas (November 2004 to November 2005).

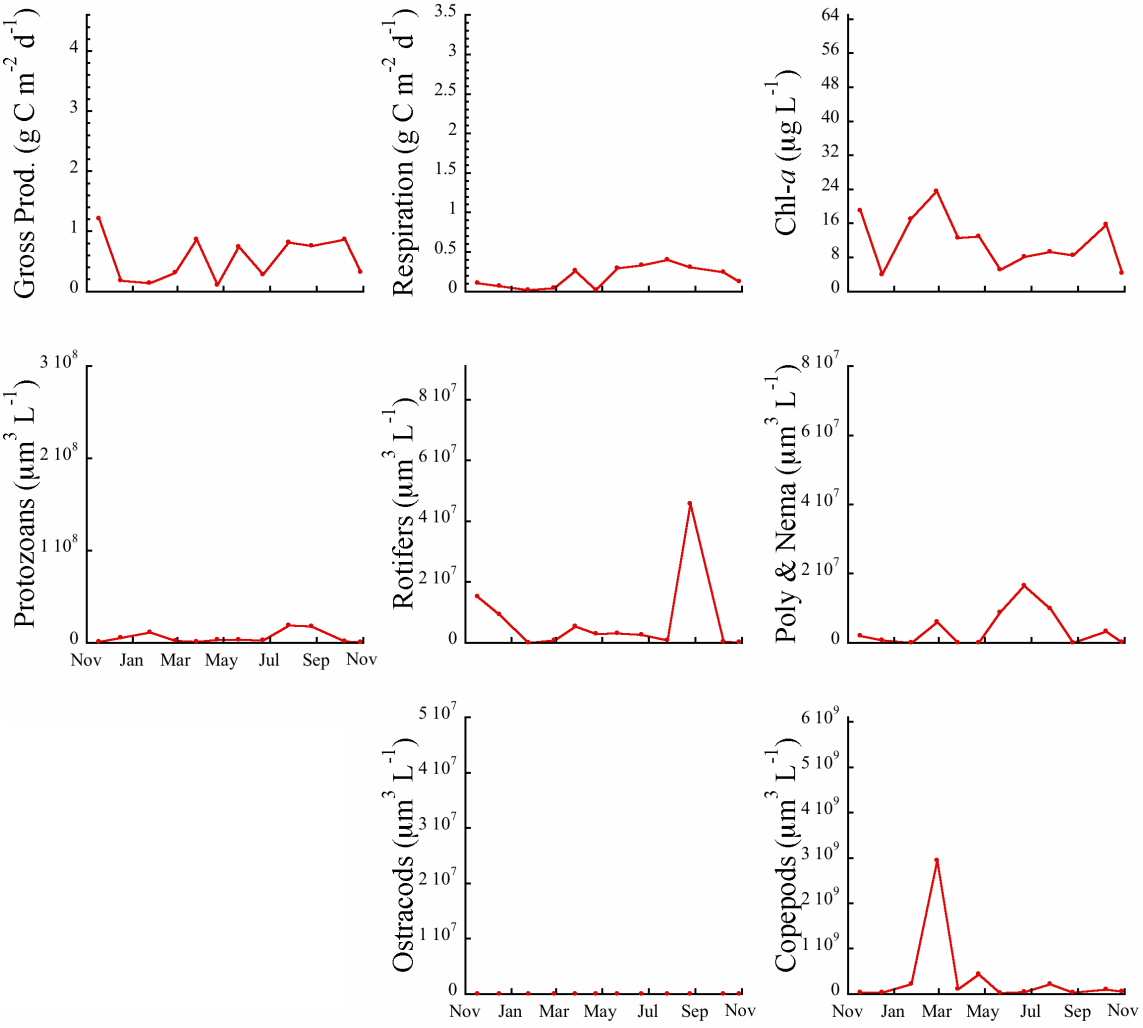

Fig. C-5. Station 5 biological parameters for Mesquite Bay, Texas (November 2004 to November 2005).

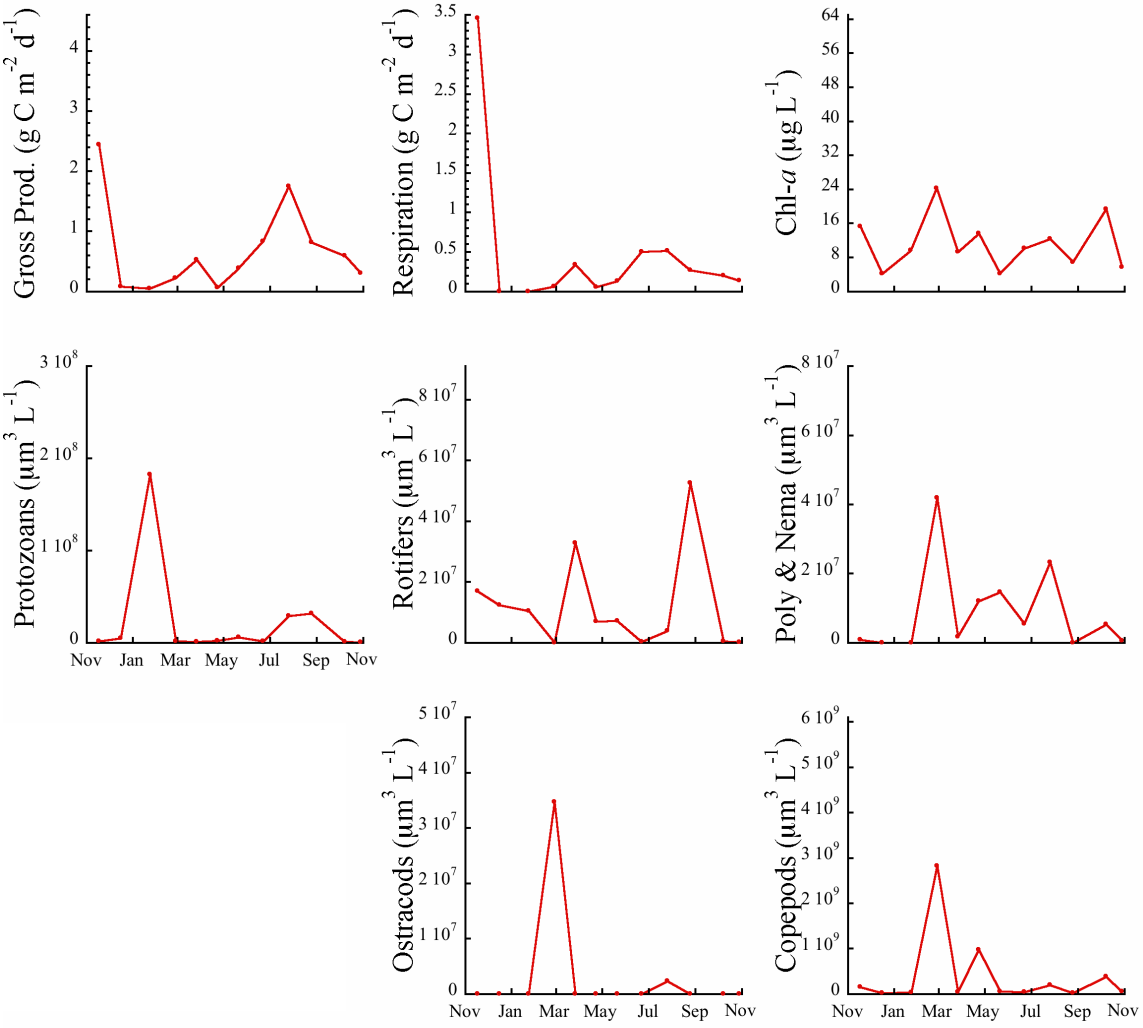

Fig. C-6. Station 6 biological parameters for Mesquite Bay, Texas (November 2004 to November 2005).

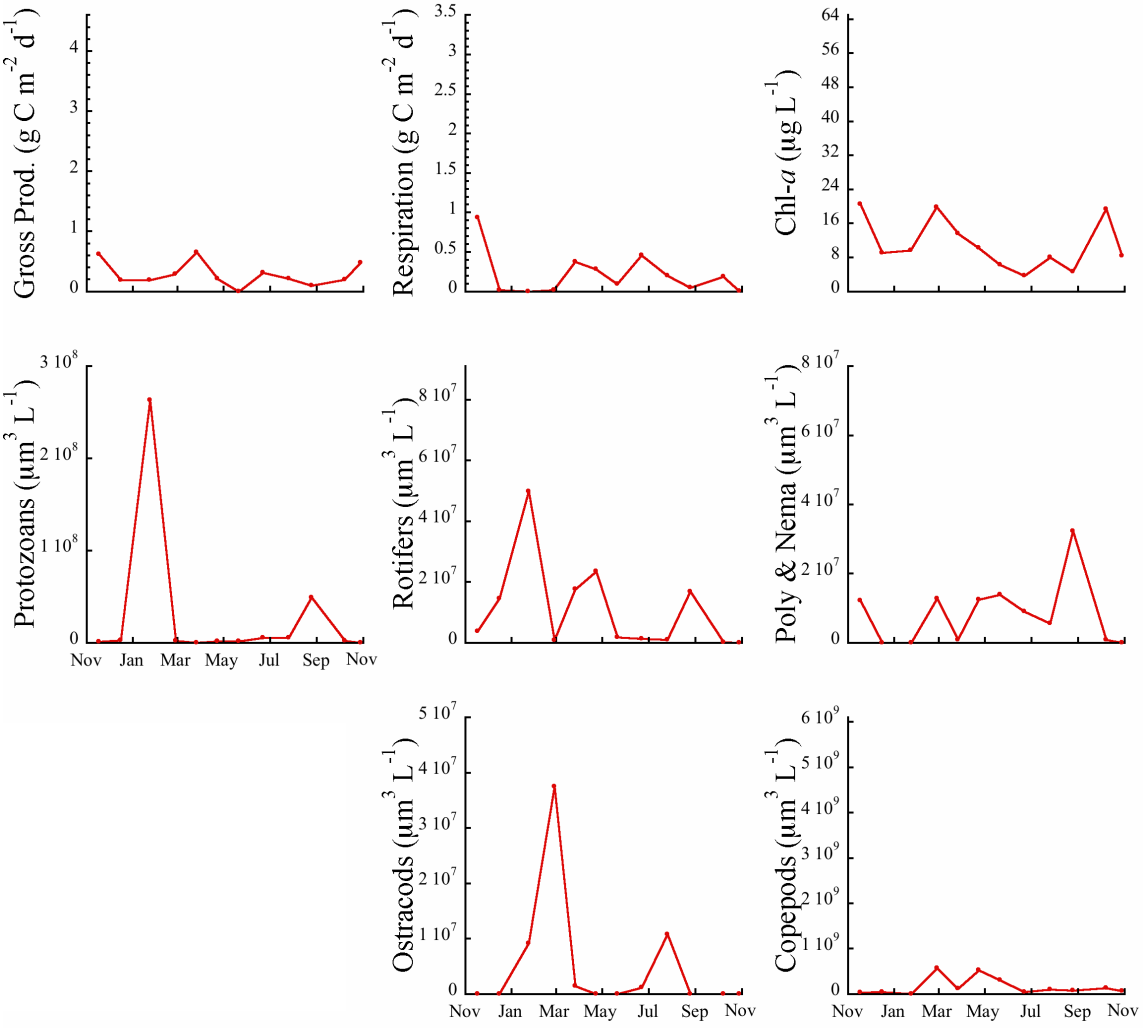

Fig. C-7. Station 7 biological parameters for Mesquite Bay, Texas (November 2004 to November 2005).

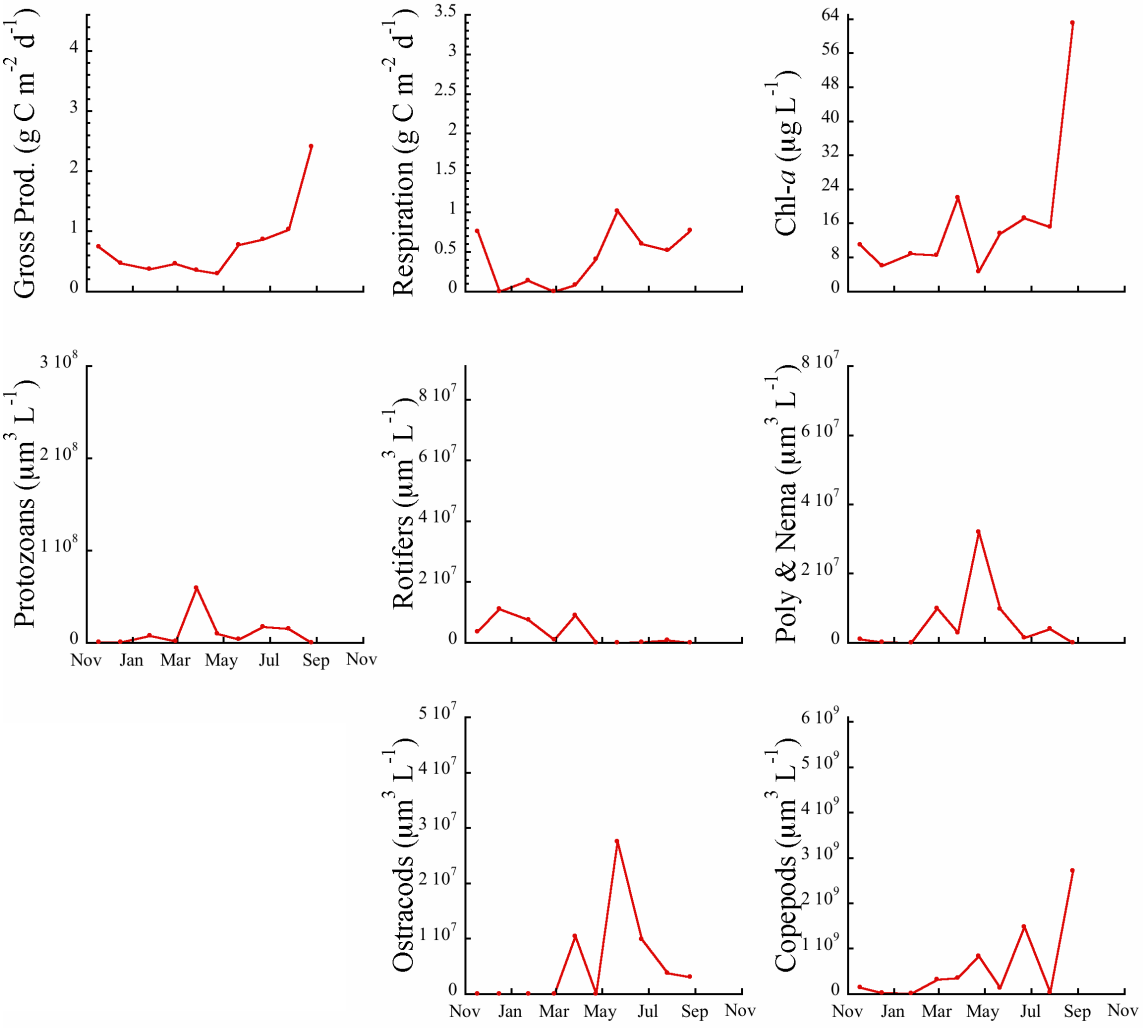

Fig. C-8. Station 8 biological parameters for Mesquite Bay, Texas (November 2004 to November 2005).

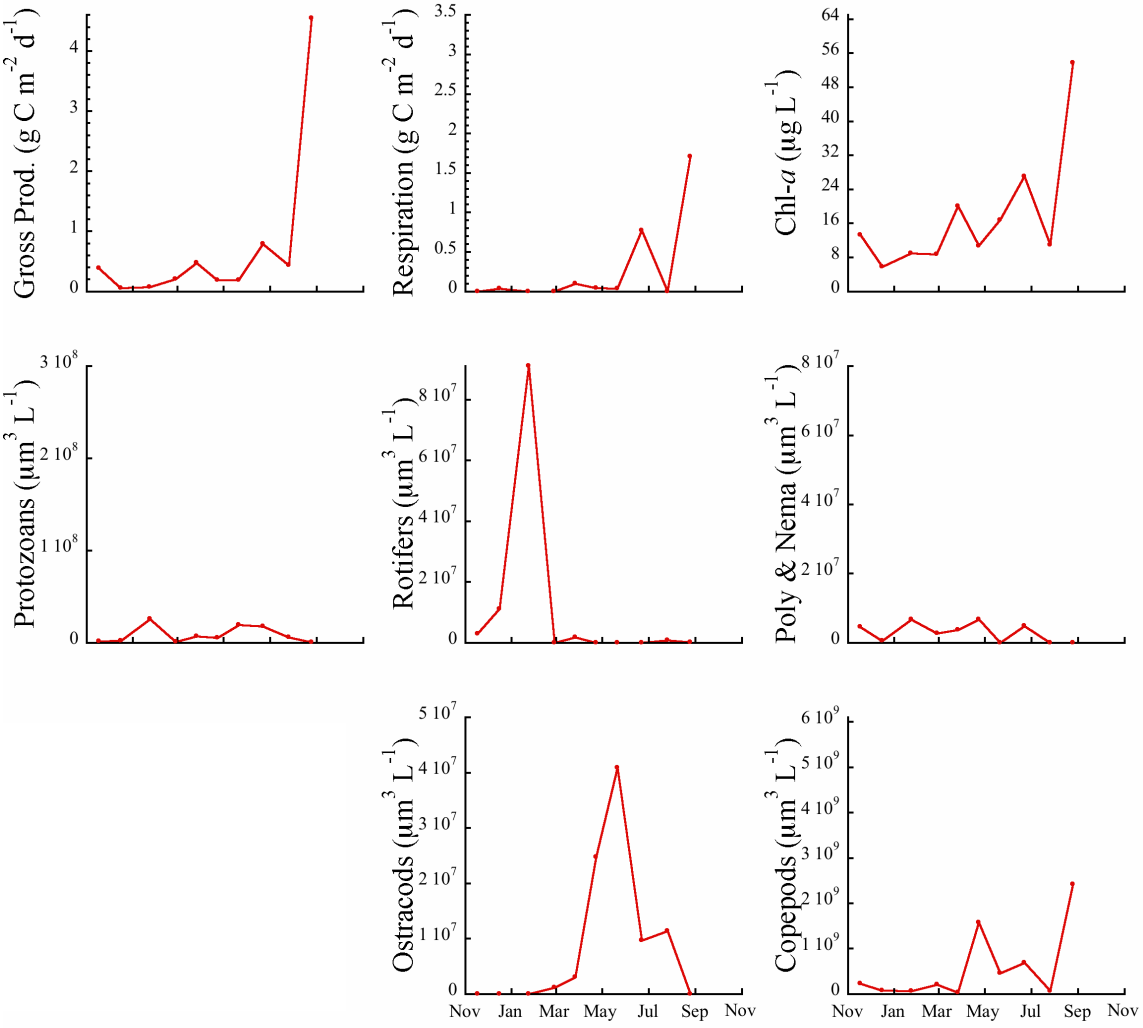

Fig. C-9. Station 9 biological parameters for Mesquite Bay, Texas (November 2004 to November 2005).

APPENDIX D

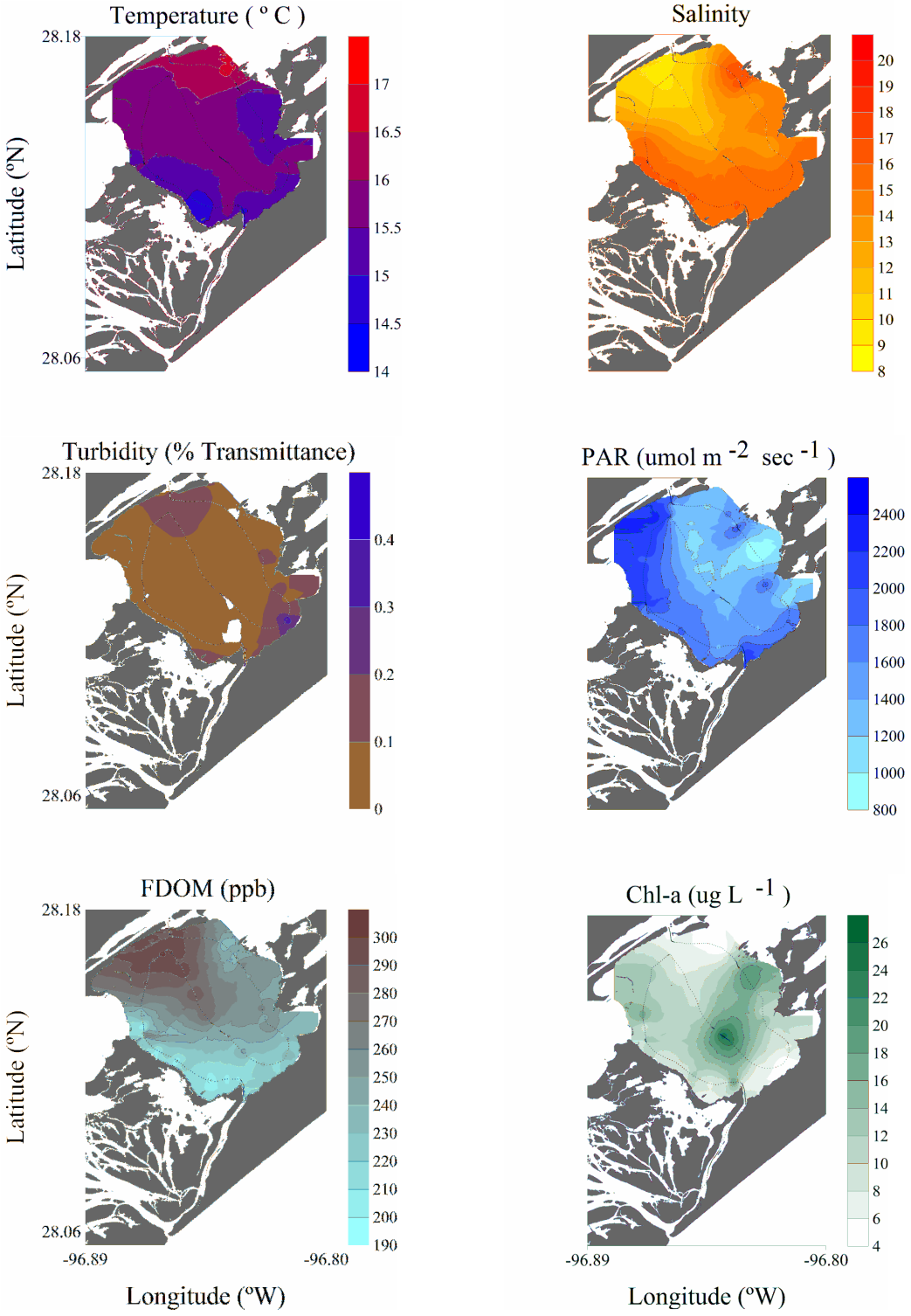

Fig. D-1. February 2005 physiochemical water parameters for Mesquite Bay, Texas.

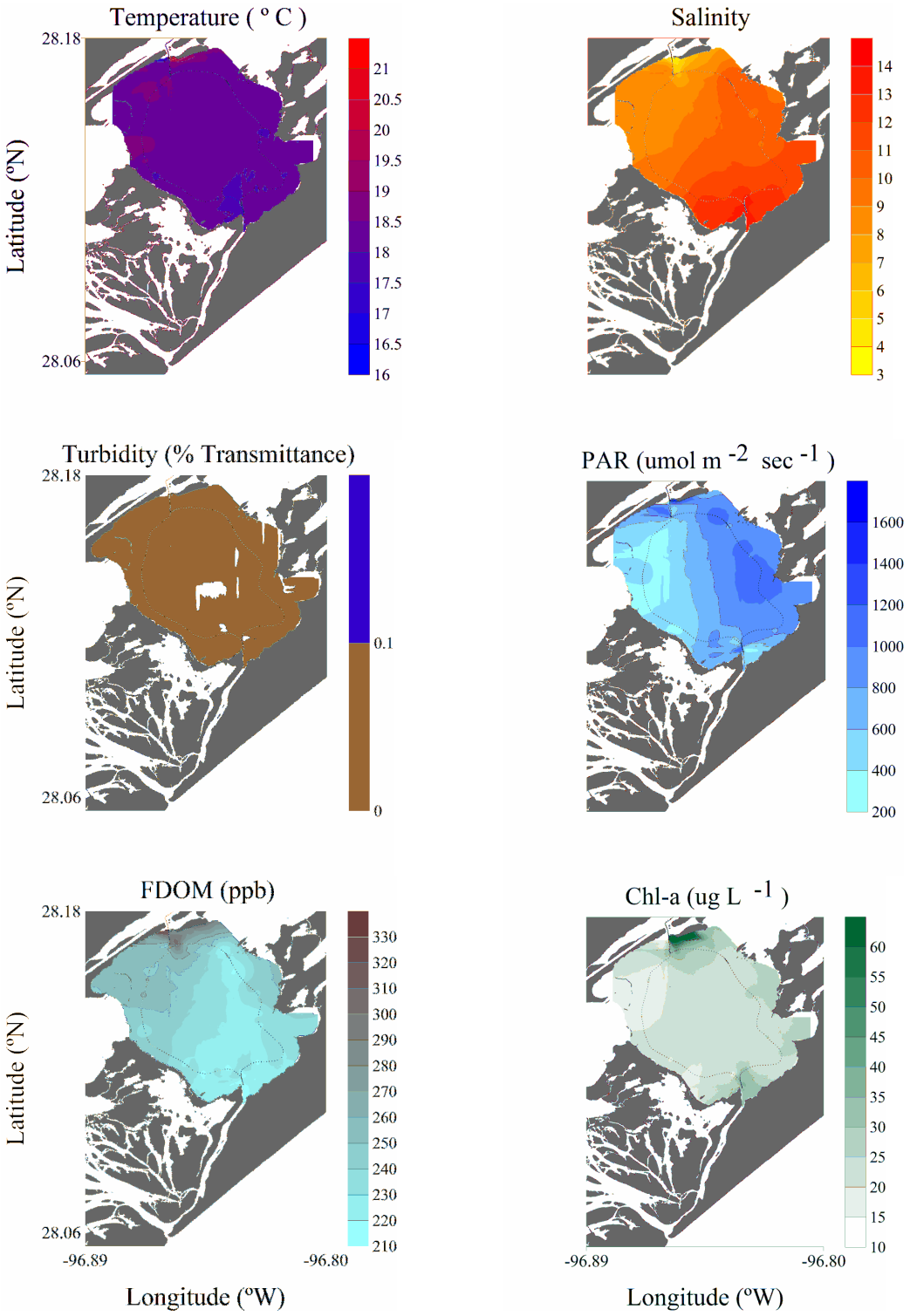

Fig. D-2. March 2005 physiochemical water parameters for Mesquite Bay, Texas.

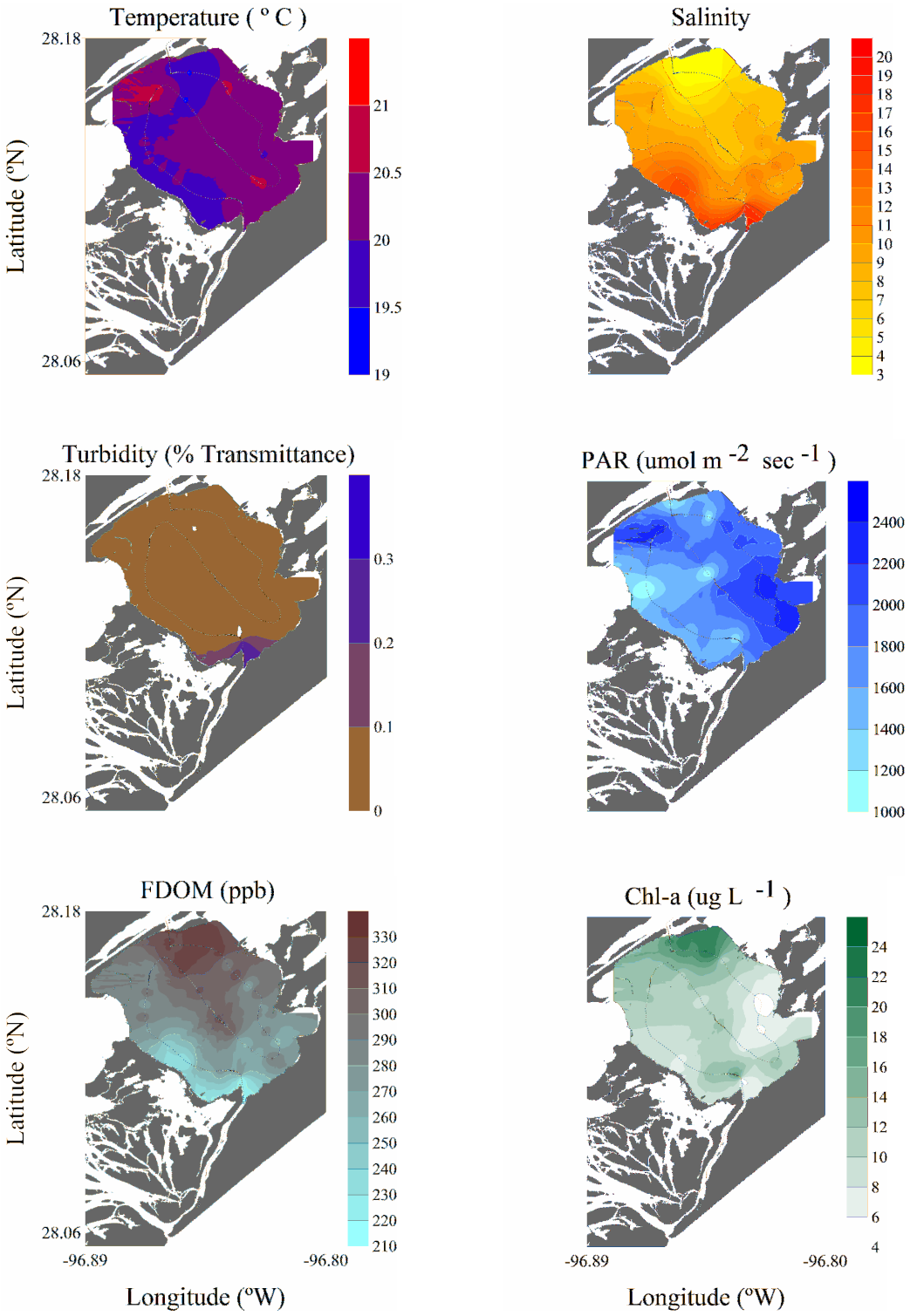

Fig. D-3. April 2005 physiochemical water parameters for Mesquite Bay, Texas.

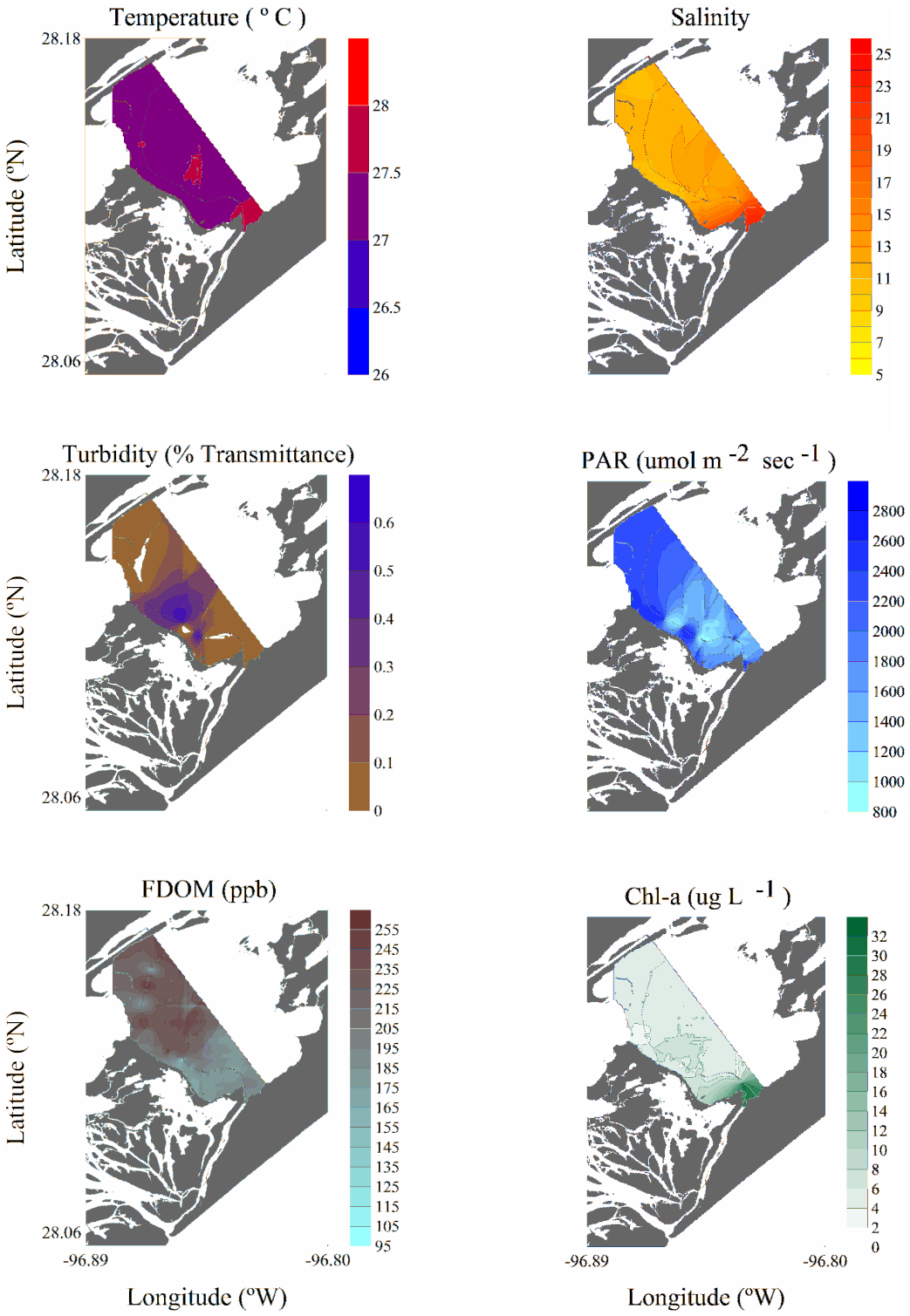

Fig. D-4. May 2005 physiochemical water parameters for Mesquite Bay, Texas.

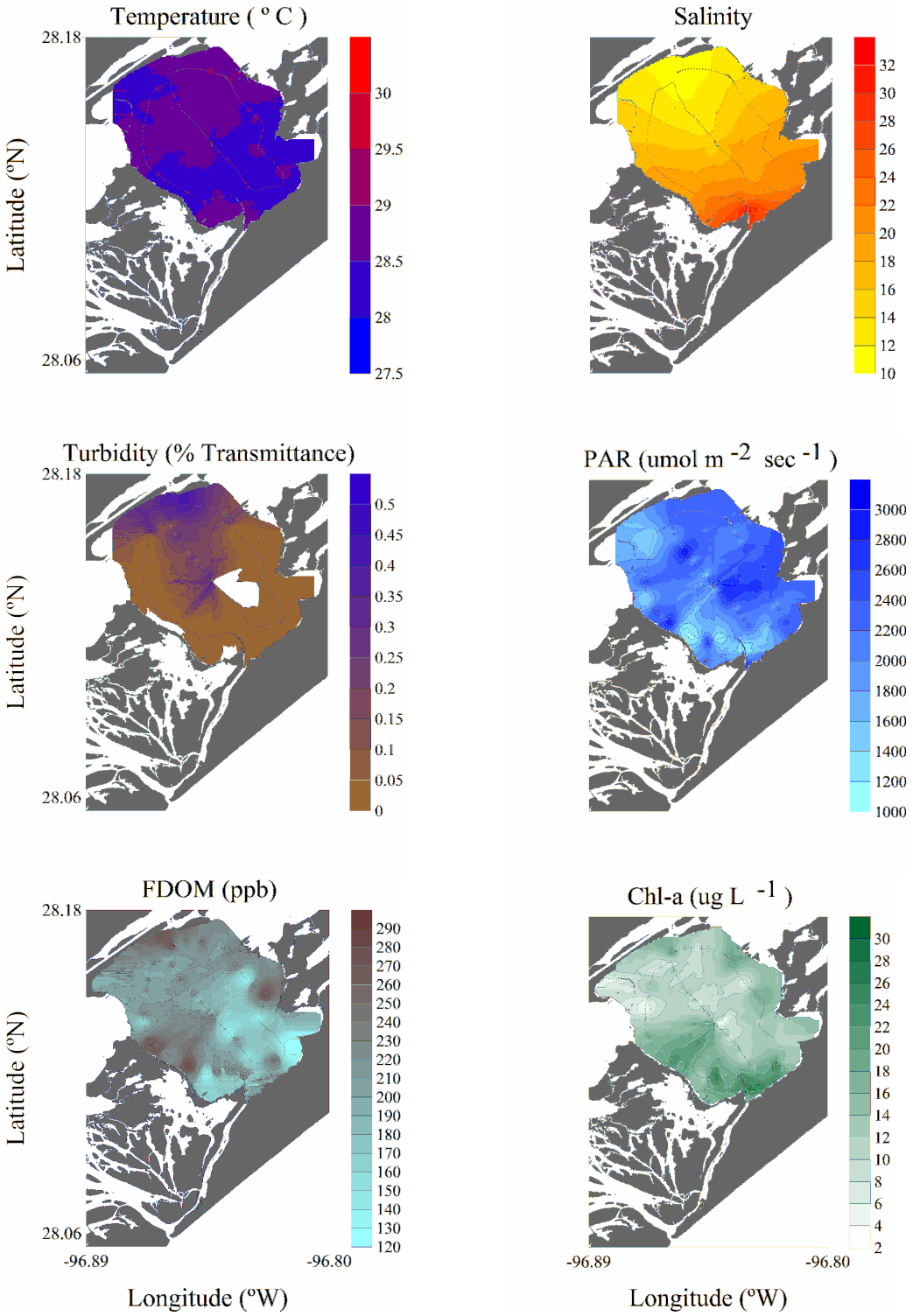

Fig. D-5. June 2005 physiochemical water parameters for Mesquite Bay, Texas.

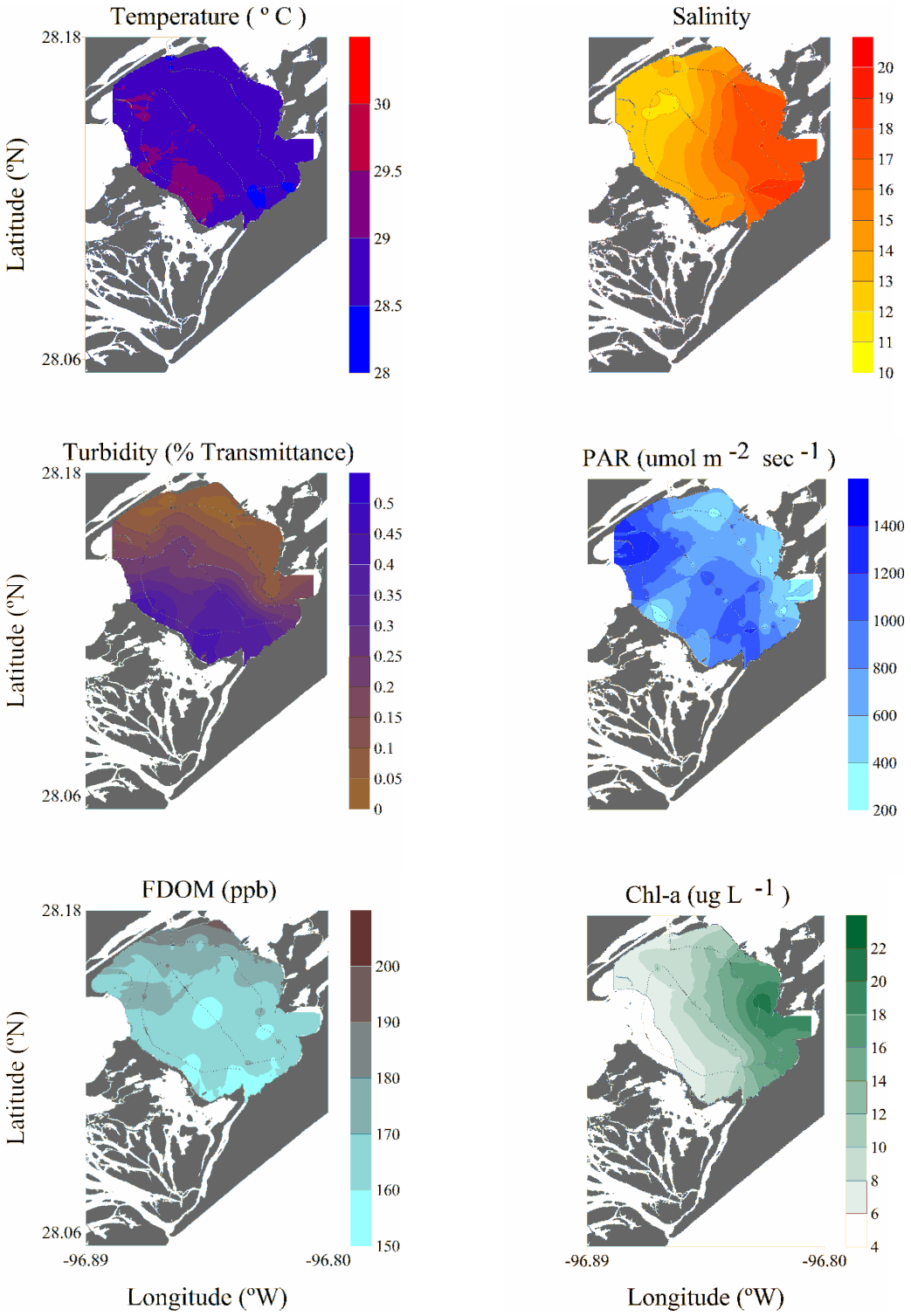

Fig. D-6. July 2005 physiochemical water parameters for Mesquite Bay, Texas.

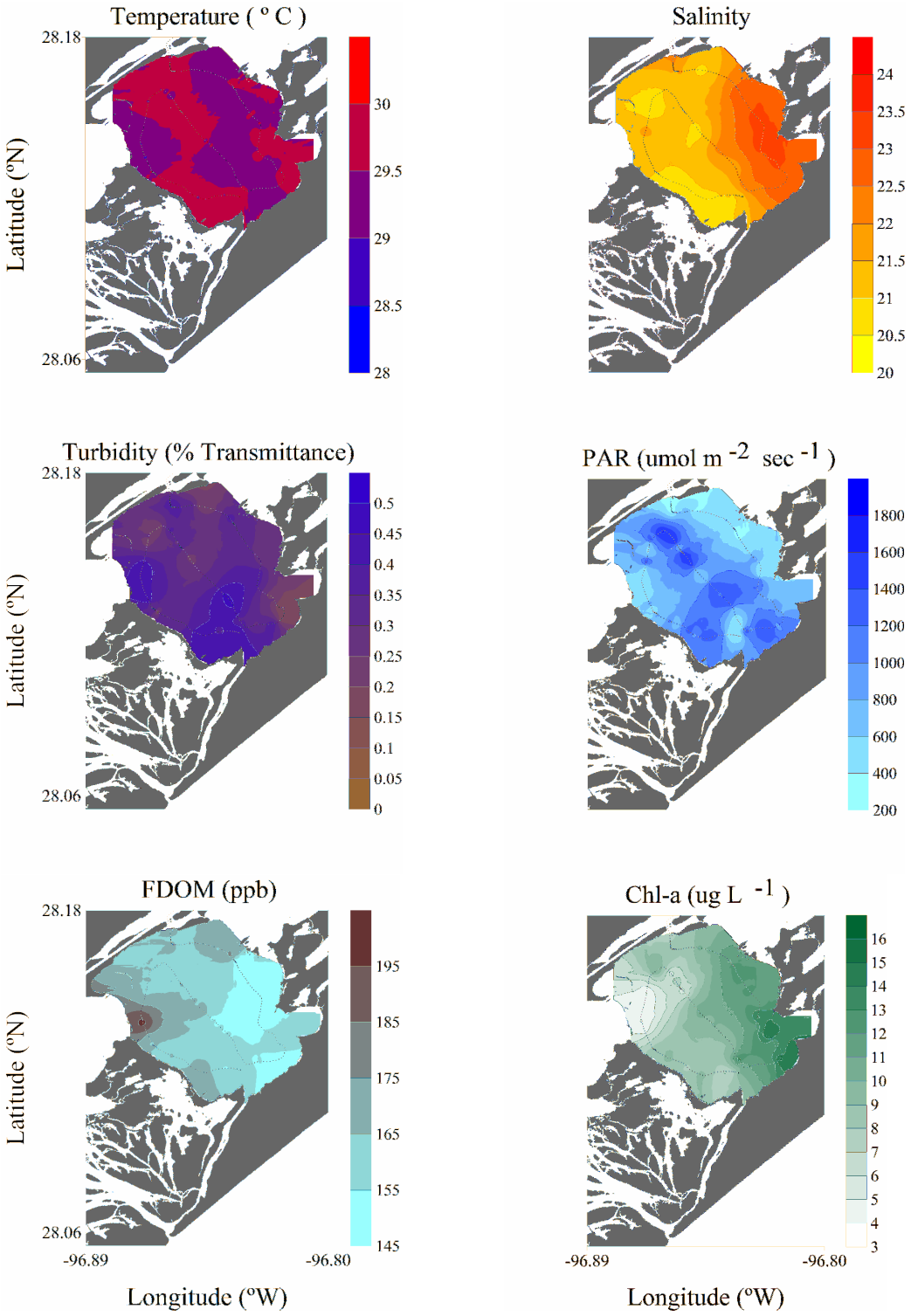

Fig. D-7. August 2005 physiochemical water parameters for Mesquite Bay, Texas.

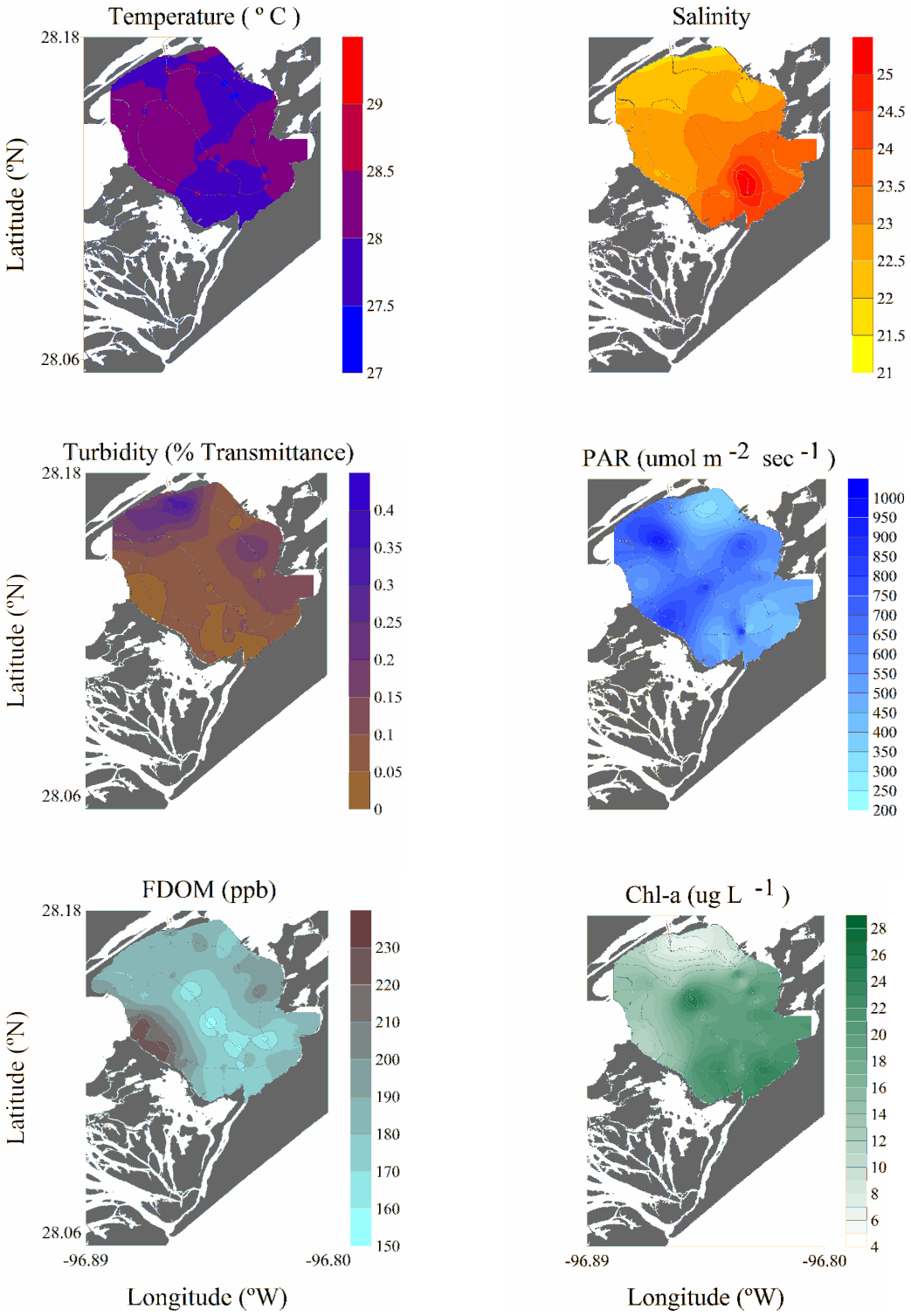

Fig. D-8. September 2005 physiochemical water parameters for Mesquite Bay, Texas.

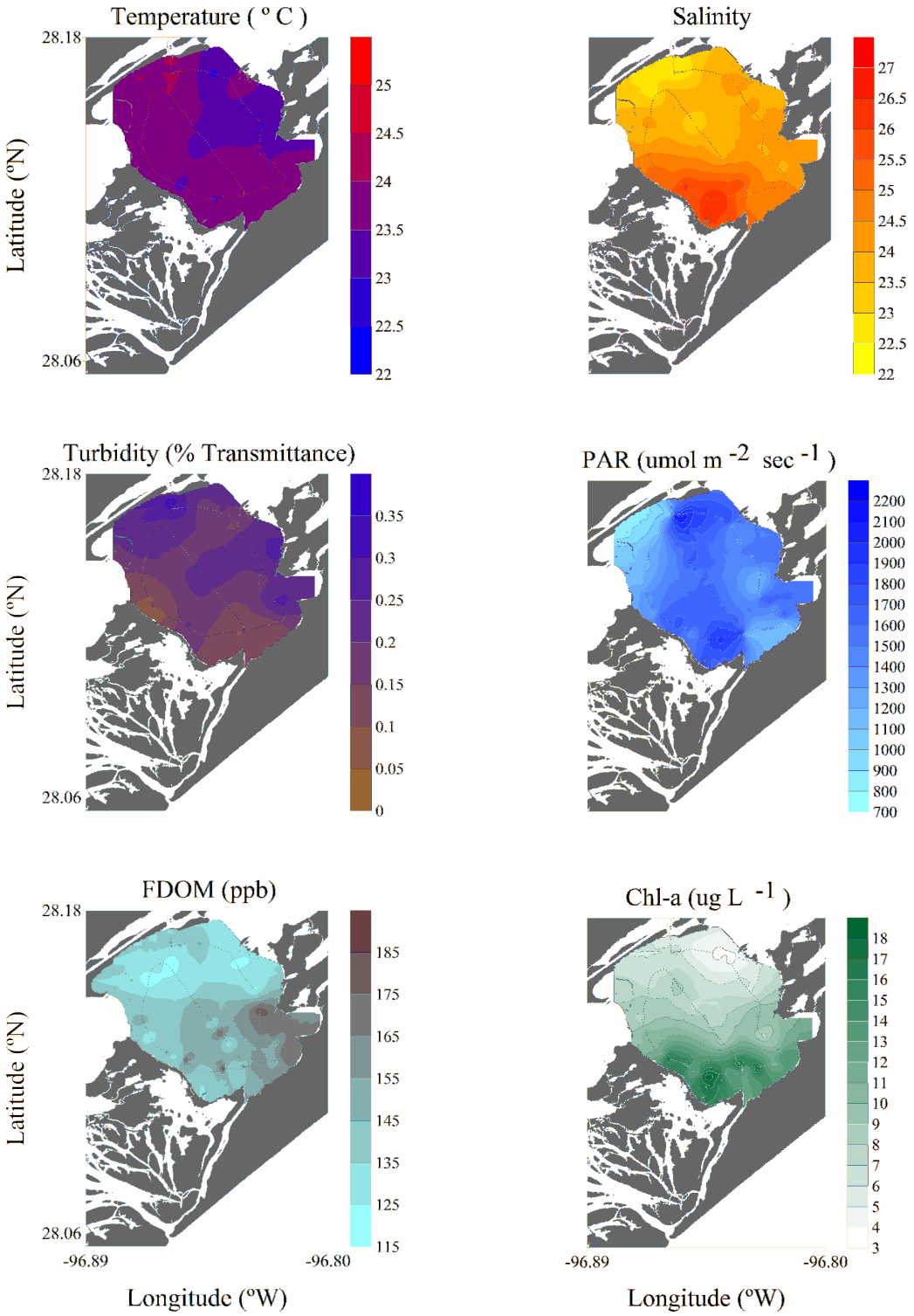

Fig. D-9. October 2005 physiochemical water parameters for Mesquite Bay, Texas.

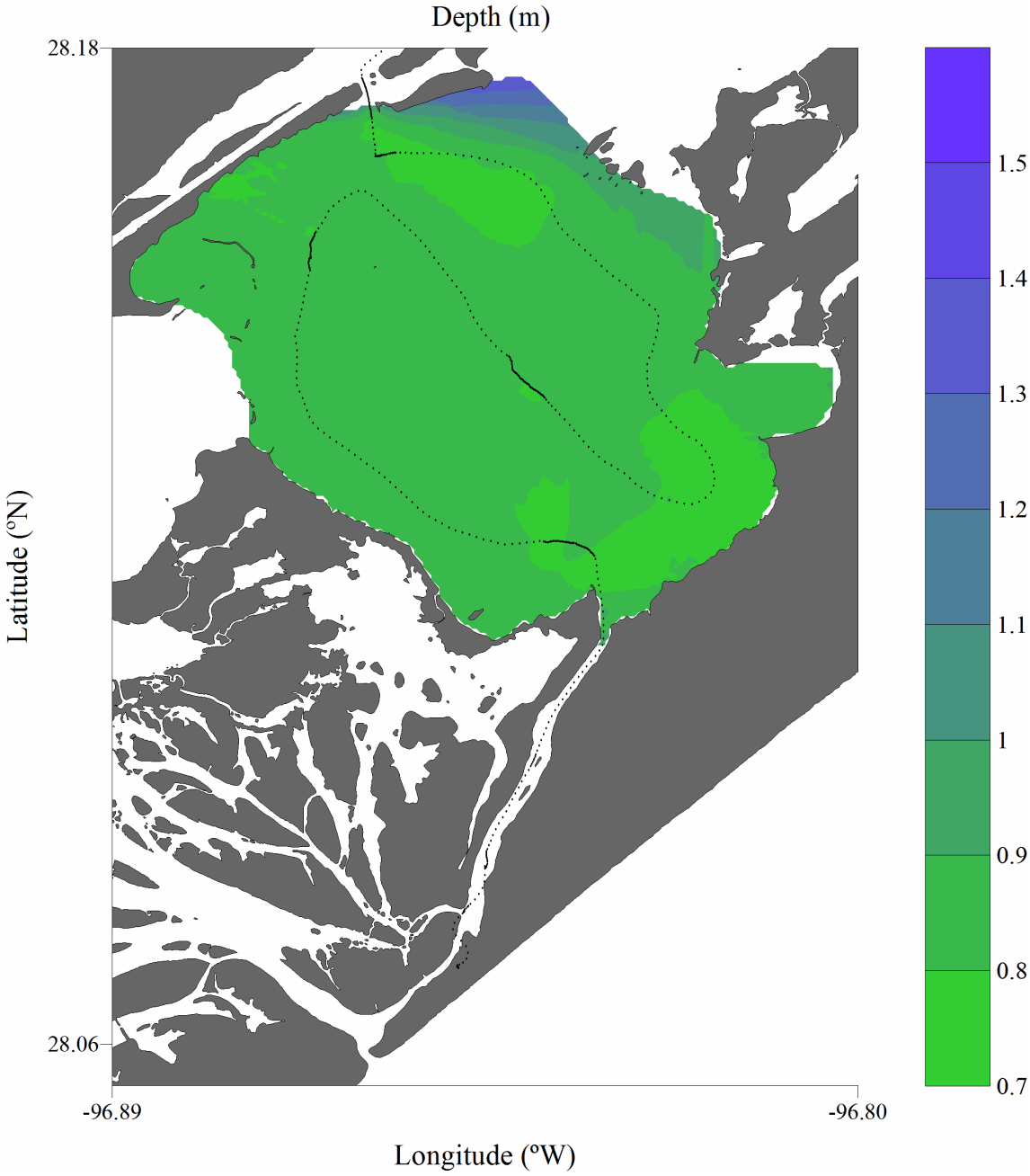

Fig. D-10. April 2005 depth profile for Mesquite Bay, Texas.

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Professional experience

2007-P Research Associate, Aquatic Ecology Laboratory, Texas A&M University, College Station, Texas.
2002 Field and Lab Assistant/Technician & Research Assistant, Aquatic Ecology Laboratory, Texas A&M University, College Station, Texas.
2002 Resource Assessment Management Personnel, Missouri Department of Conservation, Columbia, Missouri.

Research experience

2006-P Harmful algal bloom and fecal coliform research on inland water body, Aquatic Ecology Laboratory, Texas A&M University, College Station, Texas.
2004 Productivity analysis of San Antonio Bay Estuary, Aquatic Ecology Laboratory, Texas A&M University, College Station, Texas.
2003 Evaluation of carbon cycling within benthic sediments, Aquatic Ecology Laboratory, Texas A&M University, College Station, Texas.
2002 Productivity analysis of hydrologically altered salt marsh habitat in the Rincon Delta, Aquatic Ecology Laboratory, Texas A&M University, College Station Texas.
2002 Biological integrity assessment of Missouri wadeable streams and physical habitat assessment, Missouri Department of Conservation, Columbia, Missouri.

Publications

Fejes, E.M., D.L. Roelke, G. Gable, J.L. Heilman, K.J. McInnes, D.A. Zuberer. 2005. Microalgal productivity, community composition, and pelagic food web dynamics in a sub-tropical, turbid salt marsh isolated from freshwater inflow. Estuaries. 28:94-105.

Roelke D.L., J. Cotner, J.V. Montoya, C. Del Castillo, S. Davis, J. Snider, G. Gable, K.O. Winemiller. Optically determined sources of allochthonous organic matter and metabolic characterizations in a tropical oligotrophic river and associated lagoon. Journal of the North American Benthological Society. Accepted.